

METHODS AND COMPOSITIONS FOR SCREENING
USING DIPHTHERIA TOXIN CONSTRUCTS

5

FIELD OF THE INVENTION

The invention relates to methods and compositions utilizing diphtheria constructs useful in screening technologies. In particular, the methods and compositions are useful in screening for modulators of IgE synthesis, secretion and switch rearrangement.

10

BACKGROUND OF THE INVENTION

Diphtheria toxin (DT) is secreted by toxigenic strains of the corynebacterium diphtheriae as a single polypeptide chain of 58 dKA and contains three structurally and functionally distinct domains: the receptor binding domain (R, residues 387-535), the pore-forming/membrane translocating domain (T, residues 200-378) and the catalytic domain (C, residues -188). After binding its cellular receptor, HBEGF, a proteolytic activation event cleaves DT into two fragments which remain tightly associated through a single disulfide bond and noncovalent interactions. Exposure of DT to the acidic environment of endosomes triggers a conformational change which drives the insertion of the T domain into the lipid bilayer, forming a pore through which the C domain is translocated into the cytoplasm. Once free in the cytoplasm, diphtheria toxin's C domain inhibits protein synthesis by specifically ADP-ribosylating elongation factor 2. While many of the toxins within this class contain all three functional domain within a single synthesized polypeptide chain, some toxin systems, such as anthrax, have separated these functions into two or three cooperating proteins. Mechanistically, the initial insertion of the T domain resembles the early events of both the fusion and lysogenic polypeptides, whereby environmental cues trigger the exposure of hydrophobic domains capable of membrane insertion. However, the second phase of DT translocation more closely resembles cellular protein transport systems which utilize proteinaceous, aqueous channels as conduits through which partially unfolded, hydrophilic proteins can be translocated. For example, cotranslational movement of proteins into the endoplasmic reticulum utilize a dedicated channel formed by the Sec61 protein complex and similar channel systems have been described for both mitochondrial and peroxisomal protein import. Like its cellular counterpart, DT's T domain forms a pore of limited size and requires at least the partial unfolding of translocating proteins.

20

25

30

Thus, cells ectopically expressing HBEGF are capable of translocating toxin into the cytoplasm and acute cytotoxicity quickly ensues as the C domain proceeds to inhibit cellular protein synthesis by inactivating elongation factor 2 (EF-2). Cells lacking HBEGF on their surface are spared this fate and continue to thrive even in the presence of relatively high concentrations of free DT.

5

Immunoglobulins must bind to a vast array of foreign molecules and thus exist in many forms. The sequence of the variable (V) region of immunoglobulin molecules varies tremendously, conferring virtually unlimited capacity to bind antigens. The constant (C) region comes in five different varieties: α , δ , ϵ , γ and μ , providing five different isotypes: IgA, IgD, IgE, IgG and IgM, each of which performs a different set of functions. B cells initially produce only IgM and IgD, and must be activated or induced to produce the other isoforms, such as IgE.

10

The course of IgE production starts with the activation of B cells. Upon activation with an antigen, B cells follow one of two differentiation pathways: they may differentiate directly into plasma cells, which are basically antibody-secreting factories, or they may give rise to germinal centers, specialized structures within lymphoid organs. In the latter, successive rounds of mutation of the V region genes is followed by expression of the gene products on the cell surface, with selection of the cells on the basis of the affinity of the mutated immunoglobulins against the antigen.

15

In both pathways of antigen-induced B cell differentiation, isotype switching occurs in which the C region of the immunoglobulin heavy chain changes from the joint expression of IgM and IgD on naive B cells to expression of one of the downstream isotypes such as IgE. This switching involves the replacement of upstream C regions with a downstream C region that has biologically distinct effector functions without changing the structure of the variable portion and, hence, its specificity. For IgE switching, a deletional rearrangement of the Ig heavy chain gene locus occurs, a rearrangement that joins the switch region of the μ gene, S μ , with the corresponding region of the ϵ gene, S ϵ . This switching is minimally induced by IL-4 or IL-13, which initiates transcription through the S ϵ region, resulting in the synthesis of germ-line (or "sterile") ϵ transcripts; that is, transcripts of the unarranged C ϵ heavy genes. This IL-4 induced transcription is inhibited by IFN- γ , IFN- α , and TGF- β . A second signal, normally delivered by T cells, is required for actual switch recombination leading to IgE production. The T cell signal may be replaced by monoclonal antibodies to CD40, Epstein-Barr viral infection, or hydrocortisone.

20

25

30

Recently, the mechanism of class switch recombination has been explained by an accessibility model, wherein the specificity of the switch gene rearrangement is determined by the modulation of switch region accessibility; that is, the opening up of the chromatin in certain areas, allowing the required protein/enzyme complexes access to the genes.

35

IgE antibodies are crucial immune mediators of allergic reactions, and have been shown to be responsible for the induction and maintenance of allergic symptoms. For example, the introduction of anti-IgE antibodies has been shown to interfere with IgE function, thus working to alleviate allergic symptoms. See Jardieu, Current Op. Immunol. 7:779-782 (1995), Shields et al., Int. Arch. Allergy. Immunol. 107:308-312 (1995).

5

Accordingly, it is an object of the invention to provide compositions and methods useful in screening for modulators of IgE production, in particular for modulators of switch rearrangement.

10

SUMMARY OF THE INVENTION

In accordance with the objects outlined above, the present invention provides methods of screening for bioactive agents capable of inhibiting an IL-4 inducible ϵ promoter. The method comprises combining a candidate bioactive agent and a cell comprising a fusion nucleic acid. The fusion nucleic acid comprises an IL-4 inducible ϵ promoter, and a reporter gene. The promoter is then induced with IL-4 (or IL-13), and the presence or absence of the reporter protein is detected. Generally, the absence of the reporter protein indicates that the agent inhibits the IL-4 inducible ϵ promoter. The fusion nucleic acid may comprise an exogenous IL-4 inducible ϵ promoter, or an endogenous IL-4 inducible ϵ promoter. Preferred embodiments utilize the use of retroviral vectors to introduce the candidate bioactive agents.

15

20

25

In an additional aspect, the present invention provides cell lines for screening. Either CA-46 and MC-116 cell lines are included, and further comprise fusion nucleic acids comprising an IL-4 inducible ϵ promoter, and a reporter gene.

30

35

In a further aspect, the present invention provides methods of screening for bioactive agents capable of modulating IgE production. The method comprises combining a candidate bioactive agent and a cell capable of expressing IgE and determining the amount of IgE produced in the cell. Generally, a change in the amount of IgE as compared to the amount produced in the absence of the candidate agent indicates that the agent modulates IgE production. The cell can further comprise a IgE fusion protein comprises the ϵ heavy chain, and a fluorescent protein.

In an additional aspect, the invention provides methods of screening for bioactive agents capable of inhibiting a promoter of interest. The method comprises combining a candidate bioactive agent and a cell comprising a fusion nucleic acid. The fusion nucleic acid comprises a promoter of interest and a reporter gene comprising a death gene that is activated by the introduction of a ligand. The promoter is optionally induced, and the ligand is introduced to the cell. The presence of the cell is then detected, wherein the presence of the cell indicates that the agent inhibits the promoter.

In a further aspect, the invention provides compositions comprising a test vector and a reporter vector. The test vector comprises a first selection gene, and a fusion gene comprising a first sequence encoding a transcriptional activation domain, and a second sequence encoding a test protein. The reporter vector comprises a first detectable gene, and all or part of the switch ϵ sequence, which upon binding of the transcriptional activation domain due to a protein-nucleic acid interaction between the test protein and the switch ϵ sequence, will activate transcription of the first detectable gene. Methods utilizing these compositions are also provided; the methods comprise providing a host cell comprising the composition, and subjecting the host cell to conditions under which the fusion gene is expressed to produce a fusion protein. A protein-nucleic acid interaction between the fusion protein and the switch ϵ sequence is then detected.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A and 1B depict the germline ϵ locus and sequence. Fig. 1A depicts the sequence of the human IL-4 inducible ϵ promoter. Fig. 1B depicts the organization of the germline ϵ locus.

Figures 2A and 2B depict the regions (2A) and sequences (2B and 2C) of the switch ϵ (Se) region that are used in methods of screening for proteins that interact with the Se region, as described below.

Figure 3 shows a schematic of the yeast one-hybrid system used to identify proteins that bind to the Se region.

Figure 4 depicts the IL-4 induction of germline ϵ mRNA in three IgM $^+$ B cell lines, CA-46, MC-116 and DND39. The cells were incubated for 48 hours in 300 U/ml of hIL-4. RT-PCR was performed using primers specific for the germline ϵ exon and the 5'-end of the ϵ CH1 exon (predicted size is ~200 bp).

Figures 5A, 5B, 5C and 5D depict two general approaches to generate germline ϵ promoter knock-in reporter cell lines. Figure 5A shows the organization of this region in vivo. Figures 5B and 5C depict two possible knock in constructs. The IL-4 inducible IgM $^+$ B cell lines are transfected with one or both of these constructs. Under the influence of IL-4, GFP and/or BFP positive clones are isolated by FACS. Homologous recombination can be confirmed by PCR and/or Southern blot hybridization.

Figure 5D depicts an alternate construct. In this embodiment, the IL-4 inducible IgM $^+$ B cell lines are transfected with the 5D construct and selected with G418. Survivors are sorted for the lack of the 3' BFP expression (deleted during homologous recombination). RT-PCR is performed to confirm homologous recombination. Those clones are transfected with cre to remove the neomycin resistance gene.

Figure 6 depicts a preferred vector for introducing a peptide library into cell lines containing knock-in reporter genes under the control of the IL-4 inducible ϵ promoter. CRU5 is a modified LTR; Naviaux, et al., "The pCL Vector System: Rapid Production of Helper-Free, High-Titer, Recombinant Retroviruses," *Journal of Virology*, 70(8):5701-5705 (1996); LTR = long terminal repeat; ψ^+ = packaging signal; localization signal = nuclear, cell membrane, etc.; MCS = multiple cloning site; IRES = internal ribosome entry site; 2a = self-cleaving peptide. All the components are cassetted for flexibility.

Figure 7 depicts a general schematic of the generation of the primary peptide libraries in retroviruses.

Figures 8A and 8B depict constructs useful in generating ϵ heavy chain knock-in cell lines. Figure 8A depicts the wild-type organization. Figure 8B depicts a representative construct to produce a GFP knock-in. S = secretory exon; GFP = green fluorescent protein; BFP = blue fluorescent protein; Neo^r = neomycin resistance gene; VDJ = V region exon; CH1, 2, 3, 4 = constant region domain exons; M1, M2 = membrane exons; HSV-TK = Herpes Simplex Virus - thymidine kinase.

Figures 9A and 9B depict constructs useful in the invention. Figure 9A shows a reporter construct useful to create an IL-4 inducible ϵ promoter reporter cell line. CRU5 = hCMV promoter plus R and U5 regions of LTR; BGH poly A = bovine growth hormone poly-adenylation signal; SIN = self-inactivating LTR. Figure 9B shows a library construct.

Figures 10A and 10B depict a schematic of the screen for candidate agents of the germline ϵ promoter. Figure 10A: the experimental schematic. Figure 10B depicts the survival construct useful in the screen. Position 1 can be a number of different genes, including a FAS chimeric receptor outlined herein (including extracellular mouse Fas receptor or mouse CD8 receptor coupled with the human transmembrane and cytoplasmic Fas receptor), HSV-TK, p450 2B1 and p21 peptide.

Figures 11A, 11B and 11C depict preferred vectors and their sequences.

Figures 12A, 12B and 12C depict a construct useful in the present invention, comprising the a Fas survival construct (i.e. the use of a death gene). The sequence is of the inducible ϵ promoter-chimeric Fas-IRES-hygromycin-bovine growth hormone poly A tail that is put into the C12s vector backwards to that no leaky transcription happens through the cmv promoter.

Figures 13A, 13B and 13C depict a construct useful in the present invention, comprising the a Fas survival construct (i.e. the use of a death gene). The sequence is of the inducible ϵ promoter-chimeric Fas (either CD8 or mLy2)-IRES-hygromycin-bovine growth hormone poly A tail that is put into the C12s vector backwards to that no leaky transcription happens through the cmv promoter.

Figure 14 depicts the structure and mechanism of diphtheria toxin.

Figures 15A and 15B depict an additional death gene construct, comprising the Heparin-binding epidermal growth factor-like growth factor (HBEGF), which is activated by the diphtheria toxin.

5

Figure 16 shows the results of some FACS screens showing diphtheria sensitivity after of ϵ promoter activation in several cell lines.

10

Figure 18 depicts some HBEGF constructs, including Figures 18A and 18B, that utilize CD9; Figures 18C-G depict a variety of different constructs. Figure 18F can be used to screen for IRES inhibition or activation.

15

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides compositions and methods useful in screening for modulators, particularly inhibitors, of the production of IgE antibodies. In particular, assay methodologies are provided that are amenable to high-throughput screening strategies, such that large numbers of potential drugs may be screened rapidly and efficiently. Generally, traditional treatments for IgE suppression are based on regulation of the system after IgE has been made, for example using anti-IgE antibodies or anti-histamines, to modulate the IgE-mediated response resulting in mast cell degranulation. In some cases, drugs are known that generally downregulate IgE production or that inhibit switching but not induction of germline transcripts (see for example Loh et al., J. Allerg. Clin. Immunol. 97(5):1141 (1996)).

25

In contrast, the present invention provides several related techniques that may be used to screen for upstream modulators of IgE production, to prevent the production of IgE and thus reduce or eliminate the allergic response. For example, an early step in the Ig switch is the production of sterile ϵ transcripts in response to IL-4. It is also appreciated that blockage of the production of membrane bound IgE may induce programmed cell death (PCD). By interfering at this step, highly efficient, rapid and prolonged inhibition of the allergic response may occur. In addition, these techniques allow individual cell assessment and thus are useful for high-throughput screening strategies, for example those that utilize fluorescence activated cell sorting (FACS) techniques, and thus allow screening of large numbers of compounds for their effects on IgE production.

30

In a preferred embodiment, the invention relates to methods that rely on reporter genes fused to IgE promoters, such as the IL-4 inducible ϵ promoter that starts a cascade that ultimately results in IgE

35

production. Using novel reporter constructs, screening for modulators of this promoter system may be done. Thus the invention provides a number of different constructs that allow for screening for antagonists and agonists of these promoters.

5/16/06

In a preferred embodiment, the invention provides methods of screening for bioactive agents capable of modulating, particularly inhibiting, an IL-4 inducible ϵ promoter. By "an IL-4 inducible promoter" herein is meant a nucleic acid promoter that is induced by IL-4, putatively by binding an unknown IL-4 induced DNA binding protein that results in induction of the promoter; that is, the introduction of IL-4 causes the pronounced activation of a particular DNA binding protein that then binds to the IL-4 inducible promoter segment and induces transcription. The sequence of the human IL-4 inducible promoter is shown in Figure 1, and as will be appreciated by those in the art, derivatives or mutant promoters are included within this definition. Particularly included within the definition of an IL-4 inducible promoter are fragments or deletions of the sequence shown in Figure 1. As is known in the art, the IL-4 inducible promoter is also inducible by IL-13. By "modulating an IL-4 inducible promoter" herein is meant either an increase or a decrease (inhibition) of promoter activity, for example as measured by the presence or quantification of transcripts or of translation products. By "inhibiting an IL-4 inducible promoter" herein is meant a decrease in promoter activity, with changes of at least about 50% being preferred, and at least about 90% being particularly preferred.

The methods comprise combining a candidate bioactive agent and a cell or a population of cells comprising a fusion nucleic acid. The cell or cells comprise a fusion nucleic acid. In a preferred embodiment, the fusion nucleic acid comprises an IL-4 inducible ϵ promoter and at least a first reporter gene. The IL-4 inducible ϵ promoter is as described herein, for example SEQ ID NO:1, or derivatives thereof, and may be either an endogenous or exogenous IL-4 inducible ϵ promoter, as is more fully described below.

By "reporter gene" or "selection gene" herein is meant a gene that by its presence in a cell (i.e. upon expression) can allow the cell to be distinguished from a cell that does not contain the reporter gene. Reporter genes can be classified into several different types, including detection genes, survival genes, death genes and cell cycle genes. It may be the nucleic acid or the protein expression product that causes the effect. As is more fully outlined below, additional components, such as substrates, ligands, etc., may be additionally added to allow selection or sorting on the basis of the reporter gene.

In a preferred embodiment, the reporter gene encodes a protein that can be used as a direct label, i.e. a detection gene, for sorting the cells, i.e. for cell enrichment by FACS. In this embodiment, the protein product of the reporter gene itself can serve to distinguish cells that are expressing the reporter gene. In this embodiment, suitable reporter genes include those encoding green fluorescent protein (GFP; Chalfie, et al., "Green Fluorescent Protein as a Marker for Gene Expression," *Science*

263(5148):802-805 (Feb 11, 1994); and EGFP; Clontech - Genbank Accession Number U55762), blue fluorescent protein (BFP; 1. Quantum Biotechnologies, Inc. 1801 de Maisonneuve Blvd. West, 8th Floor, Montreal (Quebec) Canada H3H 1J9; 2. Stauber, R. H. Biotechniques 24(3):462-471 (1998); 3. Heim, R. and Tsien, R. Y. Curr. Biol. 6:178-182 (1996)), enhanced yellow fluorescent protein (EYFP; 1. Clontech Laboratories, Inc., 1020 East Meadow Circle, Palo Alto, CA 94303), luciferase (Ichiki, et al.), and β -galactosidase (Nolan, et al., "Fluorescence-Activated Cell Analysis and Sorting of Viable Mammalian Cells Based on Beta-D-galactosidase Activity After Transduction of Escherichia Coli LacZ," *Proc Natl Acad Sci USA* 85(8):2603-2607 (Apr 1988)).

10 Alternatively, the reporter gene encodes a protein that will bind a label that can be used as the basis of the cell enrichment (sorting); i.e. the reporter gene serves as an indirect label or detection gene. In this embodiment, the reporter gene should encode a cell-surface protein. For example, the reporter gene may be any cell-surface protein not normally expressed on the surface of the cell, such that secondary binding agents could serve to distinguish cells that contain the reporter gene from those that do not. Alternatively, albeit non-preferably, reporters comprising normally expressed cell-surface proteins could be used, and differences between cells containing the reporter construct and those without could be determined. Thus, secondary binding agents bind to the reporter protein. These secondary binding agents are preferably labelled, for example with fluors, and can be antibodies, haptens, etc. For example, fluorescently labeled antibodies to the reporter gene can be used as the label. Similarly, membrane-tethered streptavidin could serve as a reporter gene, and fluorescently-labeled biotin could be used as the label, i.e. the secondary binding agent. Alternatively, the secondary binding agents need not be labeled as long as the secondary binding agent can be used to distinguish the cells containing the construct; for example, the secondary binding agents may be used in a column, and the cells passed through, such that the expression of the reporter gene results in the cell being bound to the column, and a lack of the reporter gene (i.e. inhibition), results in the cells not being retained on the column. Other suitable reporter proteins/secondary labels include, but are not limited to, antigens and antibodies, enzymes and substrates (or inhibitors), etc.

30 In a preferred embodiment, the reporter gene is a survival gene that serves to provide a nucleic acid (or encode a protein) without which the cell cannot survive, such as drug resistant genes. In this embodiment, the assays may rely on clonal or pooled populations of cells, since if inhibitors of the promoter are found, the cells will die, necessitating a clonal population in order to determine the candidate agent.

35 In a preferred embodiment, the reporter gene is a cell cycle gene, that is, a gene that causes alterations in the cell cycle. For example, p21 protein its ligand (a collection of three proteins; see Harper, et al., "The p21 Cdk-Interacting Protein Cip1 Is a Potent Inhibitor of G1 Cyclin-Dependent Kinases," *Cell* 75:805-816 (November 19, 1993)), which does not cause death, but causes cell-cycle

arrest, such that cells containing inhibited IL-4 inducible promoters grow out much more quickly, allowing detection on this basis. As will be appreciated by those in the art, it is also possible to configure the system such that the cells containing the inhibited IL-4 inducible promoters do not grow out, and thus can be selected on this basis as well.

5

In a preferred embodiment, the reporter gene is a death gene that provides a nucleic acid that encodes a protein that causes the cells to die. Death genes fall into two basic categories: death genes that encode death proteins that require a death ligand to kill the cells, and death genes that encode death proteins that kill cells as a result of high expression within the cell, and do not require the addition of any death ligand. It is preferable that cell death requires a two-step process: the expression of the death gene and induction of the death phenotype with a signal or ligand, such that the cells may be grown up expressing the death gene, and then induced to die. A number of death genes/ligand pairs are known, including, but not limited to, the Fas receptor and Fas ligand (Bodmer, et al., "Characterization of Fas," *J Biol Chem* 272(30):18827-18833 (Jul 25, 1997); muFAS, Gonzalez-Cuadrado, et al., "Agonistic anti-Fas Antibodies Induce Glomerular Cell Apoptosis in Mice In Vivo," *Kidney Int* 51(6):1739-1746 (Jun 1997); Muruva, et al., *Hum Gene Ther*, 8(8):955 (May 1997)), (or anti-Fas receptor antibodies); p450 and cyclophosphamide (Chen, et al., "Potentiation of Cytochrome P450/Cyclophosphamide-Based Cancer Gene Therapy By Coexpression of the P450 Reductase Gene," *Cancer Res* 57(21):4830-4837 (Nov 1 1997)); thymidine kinase and gancyclovir (Stone, R., "Molecular 'Surgery' For Brain Tumors," 256(5063):1513 (June 12, 1992)), tumor necrosis factor (TNF) receptor and TNF, and HBEGF and diphtheria toxin. Alternatively, the death gene need not require a ligand, and death results from high expression of the gene; for example, the overexpression of a number of programmed cell death (PCD) proteins are known to cause cell death, including, but not limited to, caspases, bax, TRADD, FADD, SCK, MEK, etc.

25

As will be appreciated by those in the art, the use of the death genes in the manner described herein, particularly in two-step applications, allows general and high-throughput screening for inhibitors of other promoters, in addition to the IL-4 inducible ϵ promoters described herein. Thus, the present invention provides fusion nucleic acids comprising a promoter of interest operably linked to a death gene for use in screening methods. The promoter of interest can be either a constitutive promoter or an inducible promoter, such as the IL-4 inducible ϵ promoter. As will be appreciated by those in the art, any number of possible promoters could be used. Suitable promoters of interest include, but are not limited to, inducible promoters such as IL-4 ϵ promoter, promoters that are induced by cytokines or growth factors such as the interferon responsive factors 1 to 4, NFkB (Fiering, et al., "Single Cell Assay of a Transcription Factor Reveals a Threshold in Transcription Activated By Signals Emanating From the T-Cell Antigen Receptor," *Genes Dev* 4(10):1823-1834 (Oct 1990)), etc. When inducible promoters are used in this embodiment, suitable cell types are those that can be induced by the appropriate inducer, as will be appreciated by those in the art.

Preferred embodiments fall into one of three configurations. In a preferred embodiment, the promoter of interest is a constitutive promoter, and it is hooked to a death gene that requires the presence of a ligand, such as Fas or TNF. Thus, the cells can be grown up and the presence of the death gene verified due to the constitutive promoter. This is generally done by hooking the death gene up to a detection gene such as GFP or BFP, etc., using either an IRES or a protease cleavage site as is outlined below; thus, the presence of the detection gene means the death gene is also present. Verification of the presence of the death gene is preferred to keep the levels of false positives low; that is, cells that survive the screen should be due to the presence of an inhibitor of the promoter rather than a lack of the death gene.

10

Once the cells have been enriched for those containing the death gene, the candidate agents can be added (and their presence verified as well), followed by induction in the presence of IL-4, and finally by addition of the death ligand. Thus, the cell population is enriched for those cells that have an agent that inhibits the promoter and thus does not produce the death protein, i.e. those that survive.

15

In a preferred embodiment, the system used is the HBEGF/diphtheria system. This utilizes the interaction between diphtheria toxin and its cellular receptor, Heparin-binding epidermal growth factor-like growth factor (HBEGF). Diphtheria toxin (DT) is secreted by toxigenic strains of the *corynebacterium diphtheriae* as a single polypeptide chain of 58 dKA and contains three structurally and functionally distinct domains: the receptor binding domain (R, residues 387-535), the pore-forming/membrane translocating domain (T, residues 200-378) and the catalytic domain (C, residues 1-188). After binding its cellular receptor, HBEGF, a proteolytic activation event cleaves DT into two fragments which remain tightly associated through a single disulfide bond and noncovalent interactions. Exposure of DT to the acidic environment of endosomes triggers a conformational

20

change which drives the insertion of the T domain into the lipid bilayer, forming a pore through which the C domain is translocated into the cytoplasm. Once free in the cytoplasm, diphtheria toxin's C domain inhibits protein synthesis by specifically ADP-ribosylating elongation factor 2. While many of the toxins within this class contain all three functional domain within a single synthesized polypeptide chain, some toxin systems, such as anthrax, have separated these functions into two or three

25

cooperating proteins. Mechanistically, the initial insertion of the T domain resembles the early events of both the fusion and lysogenic polypeptides, whereby environmental cues trigger the exposure of hydrophobic domains capable of membrane insertion. However, the second phase of DT translocation more closely resembles cellular protein transport systems which utilize proteinaceous, aqueous channels as conduits through which partially unfolded, hydrophilic proteins can be translocated. For example, cotranslational movement of proteins into the endoplasmic reticulum utilize a dedicated channel formed by the Sec61 protein complex and similar channel systems have been described for both mitochondrial and peroxisomal protein import. Like its cellular counterpart,

30

35

DT's T domain forms a pore of limited size and requires at least the partial unfolding of translocating proteins.

Thus, in this embodiment, cells ectopically expressing HBEGF are capable of translocating toxin into the cytoplasm and acute cytotoxicity quickly ensues as the C domain proceeds to inhibit cellular protein synthesis by inactivating elongation factor 2 (EF-2). Cells lacking HBEGF on their surface are spared this fate and continue to thrive even in the presence of relatively high concentrations of free DT. By linking the HBEGF gene to the promoter of interest, particularly the IL-4 ϵ promoter, a selection system is created. Thus, for screening for inhibitors of the promoter, cells that survive DT are inhibited in that no HBEGF is present. Key advantages of DT/HBEGF systems are that there is conditional cytotoxicity, such that cell lines can be established, improved selection kinetics (including signaling dynamics, receptor down-regulation and faster iteration of screens), and there is a titratable cytotoxicity (partial versus complete signaling blockage allows for additional analysis).

Alternatively, a preferred embodiment utilizes fusion nucleic acids comprising promoters of interest that are inducible (such as the IL-4 ϵ promoter), and hooked to a death gene that requires a death ligand. The presence of the death gene is verified by inducing the promoter, causing the death gene (and preferably a detection gene) to be made. The candidate agents and death ligands are then introduced in the presence of their appropriate inducer, and the population is enriched for those cells that survive, i.e. contain an agent that inhibits the promoter and thus does not produce the death protein.

When death genes that require ligands are used, i.e. for "two step" processes, preferred embodiments utilize chimeric death genes, i.e. chimeric death receptor genes. These chimeric death receptors comprise the extracellular domain of a ligand-activated multimerizing receptor and the endogenous cytosolic domain of a death receptor gene, such as Fas or TNF. This is done to avoid endogenous activation of the death gene. The mechanism of Fas-induced cell death involves the introduction of the Fas ligand, which can bind two monomeric Fas receptors, causing the multimerization of the receptor, which activates the receptor and leads to secondary signalling resulting in caspase activation and PCD. However, as will be appreciated by those in the art, it is possible to substitute the extracellular portion of the death receptor with the extracellular portion of another ligand-activated multimerizing receptor, such that a completely different signal activates the cell to die. There are a number of known ligand-activated dimerizing receptors, including, but not limited to, the CD8 receptor, erythropoietin receptor, thrombopoietin receptor, growth hormone receptor, Fas receptor, platelet derived growth hormone receptor, epidermal growth factor receptor, leptin receptor, and a variety of interleukin receptors (including, but not limited to, IL-1, IL-2, IL-3, IL-4, IL-5, IL-6, IL-7, IL-8, IL-9, IL-11, IL-12, IL-13, IL-15, and IL-17; although the use of the IL-4 and IL-13 receptors are not preferred, since

these can be used to induce the promoter and thus does not provide a "two step" death process), low-density lipoprotein receptor, prolactin receptor, and transferrin receptor.

In a preferred embodiment, chimeric Fas receptor genes are made. The exact combination will depend on the cell type used and the receptors normally produced by these cells. For example, when using human cells or cell lines, a non-human extracellular domain and a human cytosolic domain are preferred, to prevent endogenous induction of the death gene. For example, a preferred embodiment utilizes human cells, a murine extracellular Fas receptor domain and a human cytosolic domain, such that the endogenous human Fas ligand will not activate the murine domain.

Alternatively, human extracellular domains may be used when the cells used do not endogenously produce the ligand; for example, the human EPO extracellular domain may be used when the cells do not endogenously produce EPO. (Kawaguchi, et al., *Cancer Lett.*, 116(1):53 (1997); Takebayashi, et al., *Cancer Res.*, 56(18):4164 (1996); Rudert, et al., *Biochem Biophys Res Commun.*, 204(3):1102 (1994); Rudert, et al., *DNA Cell Biol.*, 16(2):197 (1997); Takahasi, et al., *J Biol Chem.* 271(29):17555 (1996); Adam, et al., *J Biol Chem.*, 268(26):19882 (1993); Mares, et al., *Growth Factors*, 6(2):93 (1992); Seedorf, et al., *J Biol Chem.*, 266(19):12424 (1991); Heidaran, et al., *J Biol Chem.*, 265(31):18741 (1990); Okuda, et al., *J Clin Invest.* 100(7):1708 (1997); Allgood, et al., *Curr Opin Biotechnol.*, 8(4):474 (1997); Anders, et al., *J Biol Chem.*, 271(36):21758 (1996); Krishnan, et al., *Oncogene*, 13(1):125 (1996); Declercq, et al., *Cytokine*, 7(7):701 (1995); Bazzoni, et al., *Proc Natl Acad Sci U S A*, 92(12):5380 (1995); Ohashi, et al., *Proc Natl Acad Sci U S A*, 91(1):158 (1994); Desai, et al., *Cell*, 73(3):541 (1993); and Amara, et al., *Proc Natl Acad Sci U S A*, 94(20):10618 (1997)).

In addition to the extracellular domain and the cytosolic domain, these receptors have a transmembrane domain. As will be appreciated by those in the art, for chimeric death receptor genes, the transmembrane domain from any of the receptors can be used, although in general, it is preferred to use the transmembrane domain associated with the chosen cytosolic domain, to preserve the interaction of the transmembrane domain with other endogenous signalling proteins.

Thus, preferred embodiments provide fusion nucleic acids that utilize the IL-4 inducible ϵ promoter linked to a death gene, particularly a chimeric death receptor gene, that requires a death ligand for cell killing.

Alternatively, inducible promoters can be linked to "one step" death genes, i.e. death genes that upon a certain threshold expression, will kill a cell without requiring a ligand or secondary signal. In this embodiment, the inducible promoter is preferably "leaky", such that some small amount of death gene and a required secondary reporter gene such as a survival gene or a detection gene can be expressed. The cells that contain the death gene can then be selected on this basis, to avoid false

positives. Once the presence of the construct is verified, candidate agents are added (and their presence preferably verified, using a detection or selection gene as well), and the promoter is induced. The population is then enriched for those cells that contain agents that inhibit the promoter, i.e. that will survive.

5

In a preferred embodiment, additional reporter genes are used, particularly when inducible death genes are used. In a preferred embodiment, the additional reporter gene is a selection gene. The cells containing the death gene and the drug selectable gene are grown; if the appropriate drug is added to the culture, only those cells containing the resistance gene (and hence the death gene) survive. This ensures that the cells are expressing the death gene to decrease "false positives", i.e. 10 cells that do not die because they do not contain the death gene.

10

15

In an additional preferred embodiment, the additional reporter gene is a labeling gene such as GFP. The use of a detection gene allows cells to be sorted to give a population enriched for those containing the construct. As outlined above, a preferred embodiment uses "leaky" inducible promoters; that is, the cells are selected such that the IL-4 inducible promoter, even in the absence of IL-4 or IL-13, produces some GFP and death gene (for example, the Fas receptor constructs). In this embodiment, suitably "leaky" promoters are chosen such that some GFP is expressed (preferably enough to select the cells expressing the construct from those that are not), but not enough death gene is produced to cause death. While preferred embodiments utilize death genes requiring the addition of a death 20 ligand, it is well known that high levels of some death genes, even in the absence of death ligand, can cause death. Thus, for example, high levels of Fas receptor expression can cause multimerization, and thus activation, even in the absence of the Fas ligand.

20

25

30

35

In a preferred embodiment, when two reporter genes are used, they are fused together in such a way as to only require a single promoter, and thus some way of functionally separating the two genes is preferred. This can be done on the RNA level or the protein level. Preferred embodiments utilize either IRES sites (which allows the translation of two different genes on a single transcript (Kim, et al., "Construction of a Bifunctional mRNA in the Mouse By Using the Internal Ribosomal Entry Site of the Encephalomyocarditis Virus," *Molecular and Cellular Biology* 12(8):3636-3643 (Aug 1992) and McBratney, et al., "The Sequence Context of the Initiation Codon in the Encephalomyocarditis Virus Leader Modulates Efficiency of Internal Translation Initiation," *Current Opinion in Cell Biology* 5:961-965 (1993)), or a protease cleavage site (which cleaves a protein translation product into two proteins). Preferred protease cleavage sites include, but are not limited to, the 2a site (Ryan et al., *J. Gen. Virol.* 72:2727 (1991); Ryan et al., *EMBO J.* 13:928 (1994); Donnelly et al., *J. Gen. Virol.* 78:13 (1997); Hellen et al., *Biochem.* 28(26):9881 (1989); and Mattion et al., *J. Virol.* 70:8124 (1996), all of which are expressly incorporated by reference), prosequences of retroviral proteases including human immunodeficiency virus protease and sequences recognized and cleaved by trypsin (EP 578472,

Takasuga et al., J. Biochem. 112(5)652 (1992)) factor X_a (Gardella et al., J. Biol. Chem. 265(26):15854 (1990), WO 9006370), collagenase (J03280893, Tajima et al., J. Ferment. Bioeng. 72(5):362 (1991), WO 9006370), clostripain (EP 578472), subtilisin (including mutant H64A subtilisin, Forsberg et al., J. Protein Chem. 10(5):517 (1991), chymosin, yeast KEX2 protease (Bourbonnais et al., J. Bio. Chem. 263(30):15342 (1988), thrombin (Forsberg et al., supra; Abath et al., BioTechniques 10(2):178 (1991)), *Staphylococcus aureus* V8 protease or similar endoproteinase-Glu-C to cleave after Glu residues (EP 578472, Ishizaki et al., Appl. Microbiol. Biotechnol. 36(4):483 (1992)), cleavage by Nla proteinase of tobacco etch virus (Parks et al., Anal. Biochem. 216(2):413 (1994)), endoproteinase-Lys-C (U.S. Patent No. 4,414,332) and endoproteinase-Asp-N, *Neisseria* type 2 IgA 5 protease (Pohlner et al., Bio/Technology 10(7):799-804 (1992)), soluble yeast endoproteinase yscF (EP 467839), chymotrypsin (Altman et al., Protein Eng. 4(5):593 (1991)), enteropeptidase (WO 9006370), lysostaphin, a polyglycine specific endoproteinase (EP 316748), and the like. See e.g. Marston, F.A.O. (1986) Biol. Chem. J. 240, 1-12.

15 In addition to the promoter of interest, such as an IL-4 inducible ϵ promoter and reporter gene, the fusion nucleic acids may comprise additional components, including, but not limited to, other reporter genes, protein cleavage sites, internal ribosome entry (IRES) sites, AP-1 sites, and other components as will be appreciated by those in the art.

20 In addition to the above uses of death genes such as the diphtheria toxin/HBEGF system, the diphtheria toxin/HBEGF system has a number of additional uses, and can be configured in a number of different ways, some of which are shown in the figures. As for all the constructs outlined herein, the use of additional components (labels including detection and selection labels), IRES sites, protease 25 cleavage sites such as 2a and others, etc., can all be used.

25 In a preferred embodiment, the system is used to screen for inhibitors of any number of different promoters. As for the IL-4 ϵ promoter, any promoter can be linked to the HBEGF gene and used in screening. Cells that are pretreated with candidate agents that inhibit the promoter and thus the ultimate expression of the HBEGF will survive, and all others will die. Alternatively, screening for 30 agonists or activators of the promoters can also be done, if clonal populations are used; that is, in this embodiment, the "hits" will die. As will be appreciated by those in the art, any promoter, either constitutive or inducible, can be screened in this fashion, with the IL-4 ϵ promoter, the IgM promoter, mast cell promoters, TNF promoters, NFAT promoters, and leukotriene based promoters all being preferred.

35 In addition to screening for antagonists and agonists of promoters, the DT/HBEGF system finds use in a variety of additional applications. For example, in a preferred embodiment, the screening methods and constructs can be used in splice junction analysis. For example, as will be appreciated by those

in the art, the system can be designed such that only if correct splicing occurs will the HBEGF protein be made (the system may also be reversed).

Similarly, in a preferred embodiment, the DT/HBEGF system is used to screen for inhibition of IRES sites, for example to look for inhibitors of viral infection. As is outlined herein, IRES sites are used by a variety of virus for infectivity and replication. By setting up constructs whereby the IRES site is upstream of the HBEGF coding region, the inhibition of the IRES will prevent the HBEGF protein from being expressed and thus the cells will not die upon exposure to DT.

10 In a preferred embodiment, the DT/HBEGF system is used to screen for inhibition of RNA transport. The inhibition of RNA transport will result in no HBEGF being expressed and thus no susceptibility to the DT.

15 In a preferred embodiment, the DT/HBEGF system is used to screen for agonists or antagonists of translation level regulators, such as translational enhancers or 5' UTRs.

In a preferred embodiment, the DT/HBEGF system is used to screen for regulators of post-translational levels.

20 In a preferred embodiment, these constructs comprising the HBEGF gene can be fused as outlined herein to any number of detectable or selectable genes as outlined herein for other constructs, including green fluorescent protein (GFP) and all its derivatives (including those from Aquorea, Renilla and Ptilosarcus; see U.S.S.N. 60/164,592, filed 11/10/99 and its continuation-in-part application filed 11/10/00 (no serial number received yet), both of which are expressly incorporated by reference). For example, CD9 has been classified as a diphtheria receptor accessory protein, and can increase the sensitivity to diphtheria toxin up to 25 fold. CD9 is tightly associated with HBEGF on the cell surface, and it is a 27 kD cell surface protein with four transmembrane domains. It is generally expressed in pre-B cells, vascular smooth muscle, cardiac muscle and the distal tubules of kidney. Thus, CD9 fusions are included within the scope of the invention. Several suitable constructs are shown in the figures.

30 In a preferred embodiment, murine cells may be used in the screens, since DT does not recognize murine HBEGF and thus murine cells for screening may be engineered to express human HBEGF. Similarly, human "knock-outs", e.g. cells or cell lines that have been altered to prevent endogenous HBEGF from being expressed can be used.

In a preferred embodiment, the HBEGF protein and the toxin are either singly or both engineered for alterations in specificity. Interestingly, while DT does not affect murine HBEGF, there are only 5 amino

acid differences between the mouse and human HBEGF sequences. Thus, by altering either these amino acids or the amino acids with which they interact on the toxin itself, new screens can be developed. That is, by altering the specificity of one or the other or both, new constructs and methods are developed. For example, a current requirement of the system is that the cells used in the screens must be significantly lacking in endogenous HBEGF; these include CA46 cells and BJAB cells. This may be changed in a number of ways. For example, in a preferred embodiment the DT is altered to be solely specific for murine HBEGF, but significantly inactive towards human HBEGF. Thus, the human HBEGF status of the human cells is irrelevant, and by adding murine HBEGF to the human cells, the system may be used. Similarly, human HBEGF and the toxin may be simultaneously engineered such that the toxin is not effective against the human wild-type HBEGF, and thus only cells that have been engineered to contain the variant HBEGF will be susceptible to the toxin.

In a preferred embodiment, foreign constructs comprising the IL-4 inducible ϵ promoter and the reporter gene are made. By "foreign" herein is meant that the fusion nucleic acids originates outside of the cells. That is, a recombinant nucleic acid is made that contains an exogenous IL-4 inducible ϵ promoter and a reporter gene. Thus, in some circumstances, the cells will contain both exogenous and endogenous IL-4 inducible ϵ promoters. By "recombinant nucleic acid" herein is meant nucleic acid, originally formed *in vitro*, in general, by the manipulation of nucleic acid by endonucleases, in a form not normally found in nature. Thus an isolated nucleic acid, in a linear form, a nucleic acid containing components not normally joined, such as an IL-4 inducible promoter and a reporter gene, or an expression vector formed *in vitro* by ligating DNA molecules that are not normally joined, are all considered recombinant for the purposes of this invention. It is understood that once a recombinant nucleic acid is made and reintroduced into a host cell or organism, it will replicate non-recombinantly, i.e. using the *in vivo* cellular machinery of the host cell rather than *in vitro* manipulations; however, such nucleic acids, once produced recombinantly, although subsequently replicated non-recombinantly, are still considered recombinant for the purposes of the invention. In this embodiment, any cells that express an IL-4 receptor that transduces the IL-4 signal to the nucleus and alters transcription can be used. Suitable cells include, but are not limited to, human cells and cell lines that show IL-4/13 inducible production of germline ϵ transcripts, including, but not limited to, DND39 (see Watanabe, *supra*), MC-116, (Kumar, et al., "Human BCGF-12kD Functions as an Autocrine Growth Factor in Transformed B Cells," *Eur Cytokine Netw* 1(2):109 (1990)), CA-46 (Wang, et al., "UCN-01: A Potent Abrogator of G2 Checkpoint Function in Cancer Cells with Disrupted p53," *J Natl Cancer Inst* 88:956 (1996)).

This recombinant nucleic acid may be introduced to a cell in a variety of ways, as will be appreciated by those in the art, including, but not limited to, CaPO_4 precipitation, liposome fusion, lipofectin®, electroporation, viral infection, etc. The constructs may preferably stably integrate into the genome of the host cell (for example, with retroviral introduction, outlined below), or may exist either transiently or

stably in the cytoplasm (i.e. through the use of traditional plasmids, utilizing standard regulatory sequences, selection markers, etc.).

5 In a preferred embodiment, the exogenous constructs, which may be in the form of an expression vector, are added as retroviral constructs, using techniques generally described in PCT US97/01019 and PCT US97/01048, both of which are expressly incorporated by reference, and the examples.

10 In a preferred embodiment, the fusion construct comprises an endogenous IL-4 inducible ϵ promoter and an exogenous reporter gene; "endogenous" in this context means originating within the cell. That is, gene "knock-in" constructions are made, whereby an exogenous reporter gene as outlined herein is added, via homologous recombination, to the genome, such that the reporter gene is under the control of the endogenous IL-4 inducible ϵ promoter. This may be desirable to allow for the exploration and modulation of the full range of endogenous regulation, i.e. regulatory elements (particularly those flanking the promoter) other than just the IL-4 inducible ϵ promoter fragment.

15 Exemplary constructs are shown in Figures 5B and 5C, with GFP and BFP, although other reporter genes outlined herein may be used.

20 Homologous recombination may proceed in several ways. In one embodiment, traditional homologous recombination is done, with molecular biological techniques such as PCR being done to find the correct insertions. For example, gene "knock-ins" may be done as is known in the art, for example see Westphal et al., *Current Biology* 7:R530-R533 (1997), and references cited therein, all of which are expressly incorporated by reference. The use of recA mediated systems may also be done, see PCT US93/03868, hereby expressly incorporated by reference.

25 Alternatively, and preferably, the selection of the "knock ins" are done by FACS on the basis of the incorporation of a reporter gene. Thus, in a preferred embodiment, a first homologous recombination event is done to put a first reporter gene, such as GFP, into at least one allele of the cell genome. Preferably, this is a cell type that exhibits IL-4 inducible production of at least germline ϵ transcripts, so that the cells may be tested by IL-4 production for reporter gene expression. Suitable cells include, 30 but are not limited to, human cells and cell lines that show IL-4/13 inducible production of germline ϵ transcripts, including, but not limited to, DND39 (see Watanabe, *supra*), MC-116, (Kumar, et al., "Human BCGF-12kD Functions as an Autocrine Growth Factor in Transformed B Cells," *Eur Cytokine Netw* 1(2):109 (1990)), CA-46 (Wang, et al., "UCN-01: A Potent Abrogator of G2 Checkpoint Function in Cancer Cells with Disrupted p53," *J Natl Cancer Inst* 88:956 (1996)). As is noted herein, the ability of 35 MC-116 and CA-46 cells to produce germline ϵ transcripts upon IL-4/13 induction was not known prior to the present invention. Thus, preferred embodiments provide MC-116 and/or CA-46 cells comprising recombinant nucleic acid reporter constructs are outlined herein.

In a preferred embodiment, once a first endogenous promoter has been combined with an exogenous reporter construct, a second homologous recombination event may be done, preferably using a second reporter gene different from the first, such as BFP, to target the other allele of the cell genome, and tested as above.

5

Generally, IL-4 induction of the reporter genes will indicate the correct placement of the genes, which can be confirmed via sequencing such as PCR sequencing or Southern blot hybridization. In addition, preferred embodiments utilize prescreening steps to remove "leaky" cells, i.e. those showing constitutive expression of the reporter gene.

10

Thus, in a preferred embodiment, the invention provides cell lines that contain fusion nucleic acids comprising IL-4 inducible ϵ promoter operably connected to at least one reporter gene. Once made, the cell lines comprising these reporter constructs are used to screen candidate bioactive agents for the ability to modulate the production of IgE, as is outlined below.

15

The term "candidate bioactive agent" or "exogenous compound" as used herein describes any molecule, e.g., protein, oligopeptide, small organic molecule, polysaccharide, polynucleotide. Generally a plurality of assay mixtures are run in parallel with different agent concentrations to obtain a differential response to the various concentrations. Typically, one of these concentrations serves as a negative control, i.e., at zero concentration or below the level of detection.

20

Candidate agents encompass numerous chemical classes, though typically they are organic molecules, preferably small organic compounds having a molecular weight of more than 100 and less than about 2,500 daltons. Candidate agents comprise functional groups necessary for structural interaction with proteins, particularly hydrogen bonding, and typically include at least an amine, carbonyl, hydroxyl or carboxyl group, preferably at least two of the functional chemical groups. The candidate agents often comprise cyclical carbon or heterocyclic structures and/or aromatic or polyaromatic structures substituted with one or more of the above functional groups. Candidate agents are also found among biomolecules including peptides, saccharides, fatty acids, steroids, purines, pyrimidines, derivatives, structural analogs or combinations thereof. Particularly preferred are peptides.

25

Candidate agents are obtained from a wide variety of sources including libraries of synthetic or natural compounds. For example, numerous means are available for random and directed synthesis of a wide variety of organic compounds and biomolecules, including expression of randomized oligonucleotides. Alternatively, libraries of natural compounds in the form of bacterial, fungal, plant and animal extracts are available or readily produced. Additionally, natural or synthetically produced libraries and compounds are readily modified through conventional chemical, physical and

30

35

biochemical means. Known pharmacological agents may be subjected to directed or random chemical modifications, such as acylation, alkylation, esterification, amidification to produce structural analogs.

- 5 In a preferred embodiment, the candidate bioactive agents are proteins. By "protein" herein is meant at least two covalently attached amino acids, which includes proteins, polypeptides, oligopeptides and peptides. The protein may be made up of naturally occurring amino acids and peptide bonds, or synthetic peptidomimetic structures. Thus "amino acid", or "peptide residue", as used herein means both naturally occurring and synthetic amino acids. For example, homo-phenylalanine, citrulline and 10 noreleucine are considered amino acids for the purposes of the invention. "Amino acid" also includes imino acid residues such as proline and hydroxyproline. The side chains may be in either the (R) or the (S) configuration. In the preferred embodiment, the amino acids are in the (S) or L-configuration. If non-naturally occurring side chains are used, non-amino acid substituents may be used, for example to prevent or retard *in vivo* degradations.
- 15 In a preferred embodiment, the candidate bioactive agents are naturally occurring proteins or fragments of naturally occurring proteins. Thus, for example, cellular extracts containing proteins, or random or directed digests of proteinaceous cellular extracts, may be used. In this way libraries of prokaryotic and eucaryotic proteins may be made for screening in the systems described herein.
- 20 Particularly preferred in this embodiment are libraries of bacterial, fungal, viral, and mammalian proteins, with the latter being preferred, and human proteins being especially preferred.
- 25 In a preferred embodiment, the candidate bioactive agents are peptides of from about 5 to about 30 amino acids, with from about 5 to about 20 amino acids being preferred, and from about 7 to about 15 being particularly preferred. The peptides may be digests of naturally occurring proteins as is outlined above, random peptides, or "biased" random peptides. By "randomized" or grammatical equivalents herein is meant that each nucleic acid and peptide consists of essentially random nucleotides and amino acids, respectively. Since generally these random peptides (or nucleic acids, discussed below) are chemically synthesized, they may incorporate any nucleotide or amino acid at any position. The 30 synthetic process can be designed to generate randomized proteins or nucleic acids, to allow the formation of all or most of the possible combinations over the length of the sequence, thus forming a library of randomized candidate bioactive proteinaceous agents.
- 35 In one embodiment, the library is fully randomized, with no sequence preferences or constants at any position. In a preferred embodiment, the library is biased. That is, some positions within the sequence are either held constant, or are selected from a limited number of possibilities. For example, in a preferred embodiment, the nucleotides or amino acid residues are randomized within a defined class, for example, of hydrophobic amino acids, hydrophilic residues, sterically biased (either

small or large) residues, towards the creation of cysteines, for cross-linking, prolines for SH-3 domains, serines, threonines, tyrosines or histidines for phosphorylation sites, etc., or to purines, etc.

In a preferred embodiment, the candidate bioactive agents are nucleic acids. By "nucleic acid" or "oligonucleotide" or grammatical equivalents herein means at least two nucleotides covalently linked together. A nucleic acid of the present invention will generally contain phosphodiester bonds, although in some cases, as outlined below, nucleic acid analogs are included that may have alternate backbones, comprising, for example, phosphoramido (Beaucage, *et al.*, *Tetrahedron*, **49**(10):1925 (1993) and references therein; Letsinger, *J. Org. Chem.*, **35**:3800 (1970); Sprinzl, *et al.*, *Eur. J. Biochem.*, **81**:579 (1977); Letsinger, *et al.*, *Nucl. Acids Res.*, **14**:3487 (1986); Sawai, *et al.*, *Chem. Lett.*, 805 (1984), Letsinger, *et al.*, *J. Am. Chem. Soc.*, **110**:4470 (1988); and Pauwels, *et al.*, *Chemica Scripta*, **26**:141 (1986)), phosphorothioate (Mag, *et al.*, *Nucleic Acids Res.*, **19**:1437 (1991); and U.S. Patent No. 5,644,048), phosphorodithioate (Bruylants, *et al.*, *J. Am. Chem. Soc.*, **111**:2321 (1989)), O-methylphosphoroamidite linkages (see Eckstein, *Oligonucleotides and Analogues: A Practical Approach*, Oxford University Press), and peptide nucleic acid backbones and linkages (see Egholm, *J. Am. Chem. Soc.*, **114**:1895 (1992); Meier, *et al.*, *Chem. Int. Ed. Engl.*, **31**:1008 (1992); Nielsen, *Nature*, **365**:566 (1993); Carlsson, *et al.*, *Nature*, **380**:207 (1996), all of which are incorporated by reference)). Other analog nucleic acids include those with positive backbones (Denpcy, *et al.*, *Proc. Natl. Acad. Sci. USA*, **92**:6097 (1995)); non-ionic backbones (U.S. Patent Nos. 5,386,023; 5,637,684; 5,602,240; 5,216,141; and 4,469,863; Kiedrowski, *et al.*, *Angew. Chem. Intl. Ed. English*, **30**:423 (1991); Letsinger, *et al.*, *J. Am. Chem. Soc.*, **110**:4470 (1988); Letsinger, *et al.*, *Nucleoside & Nucleotide*, **13**:1597 (1994); Chapters 2 and 3, ASC Symposium Series 580, "Carbohydrate Modifications in Antisense Research", Ed. Y.S. Sanghui and P. Dan Cook; Mesmaeker, *et al.*, *Bioorganic & Medicinal Chem. Lett.*, **4**:395 (1994); Jeffs, *et al.*, *J. Biomolecular NMR*, **34**:17 (1994); *Tetrahedron Lett.*, **37**:743 (1996)) and non-ribose backbones, including those described in U.S. Patent Nos. 5,235,033 and 5,034,506, and Chapters 6 and 7, ASC Symposium Series 580, "Carbohydrate Modifications in Antisense Research", Ed. Y.S. Sanghui and P. Dan Cook. Nucleic acids containing one or more carbocyclic sugars are also included within the definition of nucleic acids (see Jenkins, *et al.*, *Chem. Soc. Rev.*, (1995) pp. 169-176). Several nucleic acid analogs are described in Rawls, C & E News, June 2, 1997, page 35. All of these references are hereby expressly incorporated by reference. These modifications of the ribose-phosphate backbone may be done to facilitate the addition of additional moieties such as labels, or to increase the stability and half-life of such molecules in physiological environments. In addition, mixtures of naturally occurring nucleic acids and analogs can be made. Alternatively, mixtures of different nucleic acid analogs, and mixtures of naturally occurring nucleic acids and analogs may be made. The nucleic acids may be single stranded or double stranded, as specified, or contain portions of both double stranded or single stranded sequence. The nucleic acid may be DNA, both genomic and cDNA, RNA or a hybrid, where the

nucleic acid contains any combination of deoxyribo- and ribo-nucleotides, and any combination of bases, including uracil, adenine, thymine, cytosine, guanine, inosine, xanthanine hypoxanthanine, isocytosine, isoguanine, etc.

5 As described above generally for proteins, nucleic acid candidate bioactive agents may be naturally occurring nucleic acids, random nucleic acids, or "biased" random nucleic acids. For example, digests of prokaryotic or eucaryotic genomes may be used as is outlined above for proteins.

10 In a preferred embodiment, the candidate bioactive agents are organic chemical moieties, a wide variety of which are available in the literature.

15 In a preferred embodiment, a library of different candidate bioactive agents are used. Preferably, the library should provide a sufficiently structurally diverse population of randomized agents to effect a probabilistically sufficient range of diversity to allow binding to a particular target. Accordingly, an interaction library should be large enough so that at least one of its members will have a structure that gives it affinity for the target. Although it is difficult to gauge the required absolute size of an interaction library, nature provides a hint with the immune response: a diversity of 10^7 - 10^8 different antibodies provides at least one combination with sufficient affinity to interact with most potential antigens faced by an organism. Published *in vitro* selection techniques have also shown that a library size of 20 10^7 to 10^8 is sufficient to find structures with affinity for the target. A library of all combinations of a peptide 7 to 20 amino acids in length, such as generally proposed herein, has the potential to code for 20^7 (10^9) to 20^{20} . Thus, with libraries of 10^7 to 10^8 different molecules the present methods allow a "working" subset of a theoretically complete interaction library for 7 amino acids, and a subset of shapes for the 20^{20} library. Thus, in a preferred embodiment, at least 10^6 , preferably at least 10^7 , 25 more preferably at least 10^8 and most preferably at least 10^9 different sequences are simultaneously analyzed in the subject methods. Preferred methods maximize library size and diversity.

30 The candidate bioactive agents are combined or added to a cell or population of cells. Suitable cell types for different embodiments are outlined above. By "population of cells" herein is meant at least two cells, with at least about 10^5 being preferred, at least about 10^6 being particularly preferred, and at least about 10^7 , 10^8 and 10^9 being especially preferred.

35 The candidate bioactive agent and the cells are combined. As will be appreciated by those in the art, this may be accomplished in any number of ways, including adding the candidate agents to the surface of the cells, to the media containing the cells, or to a surface on which the cells are growing or in contact with; adding the agents into the cells, for example by using vectors that will introduce the agents into the cells (i.e. when the agents are nucleic acids or proteins).

In a preferred embodiment, the candidate bioactive agents are either nucleic acids or proteins (proteins in this context includes proteins, oligopeptides, and peptides) that are introduced into the host cells using retroviral vectors, as is generally outlined in PCT US97/01019 and PCT US97/01048, both of which are expressly incorporated by reference. Generally, a library of retroviral vectors is made 5 using retroviral packaging cell lines that are helper-defective and are capable of producing all the necessary trans proteins, including gag, pol and env, and RNA molecules that have in cis the ψ packaging signal. Briefly, the library is generated in a retrovirus DNA construct backbone; standard oligonucleotide synthesis is done to generate either the candidate agent or nucleic acid encoding a protein, for example a random peptide, using techniques well known in the art. After generation of the 10 DNA library, the library is cloned into a first primer. The first primer serves as a "cassette", which is inserted into the retroviral construct. The first primer generally contains a number of elements, including for example, the required regulatory sequences (e.g. translation, transcription, promoters, etc), fusion partners, restriction endonuclease (cloning and subcloning) sites, stop codons (preferably in all three frames), regions of complementarity for second strand priming (preferably at the end of the 15 stop codon region as minor deletions or insertions may occur in the random region), etc.

A second primer is then added, which generally consists of some or all of the complementarity region to prime the first primer and optional necessary sequences for a second unique restriction site for subcloning. DNA polymerase is added to make double-stranded oligonucleotides. The double-stranded oligonucleotides are cleaved with the appropriate subcloning restriction endonucleases and subcloned into the target retroviral vectors, described below.

20 Any number of suitable retroviral vectors may be used. Generally, the retroviral vectors may include: 25 selectable marker genes under the control of internal ribosome entry sites (IRES) that greatly facilitates the selection of cells expressing peptides at uniformly high levels; and promoters driving expression of a second gene, placed in sense or anti-sense relative to the 5' LTR. Suitable selection genes include, but are not limited to, neomycin, blastocidin, bleomycin, puromycin, and hygromycin resistance genes, as well as self-fluorescent markers such as green fluorescent protein, enzymatic markers such as lacZ, and surface proteins such as CD8, etc.

30 Preferred vectors include a vector based on the murine stem cell virus (MSCV) (see Hawley et al., Gene Therapy 1:136 (1994)) and a modified MFG virus (Rivere et al., Genetics 92:6733 (1995)), and pBABE, outlined in the examples.

35 The retroviruses may include inducible and constitutive promoters for the expression of the candidate agent (to be distinguished from the IL-4 inducible ϵ promoter). For example, there are situations wherein it is necessary to induce peptide expression only during certain phases of the selection process. A large number of both inducible and constitutive promoters are known.

In addition, it is possible to configure a retroviral vector to allow inducible expression of retroviral inserts after integration of a single vector in target cells; importantly, the entire system is contained within the single retrovirus. Tet-inducible retroviruses have been designed incorporating the Self-Inactivating (SIN) feature of 3' LTR enhancer/promoter retroviral deletion mutant (Hoffman et al., 5 PNAS USA 93:5185 (1996)). Expression of this vector in cells is virtually undetectable in the presence of tetracycline or other active analogs. However, in the absence of Tet, expression is turned on to maximum within 48 hours after induction, with uniform increased expression of the whole population of cells that harbor the inducible retrovirus, indicating that expression is regulated uniformly within the infected cell population. A similar, related system uses a mutated Tet DNA-binding domain such that 10 it binds DNA in the presence of Tet, and was removed in the absence of Tet. Either of these systems is suitable.

In a preferred embodiment, the candidate bioactive agents are linked to a fusion partner. By "fusion partner" or "functional group" herein is meant a sequence that is associated with the candidate 15 bioactive agent, that confers upon all members of the library in that class a common function or ability. Fusion partners can be heterologous (i.e. not native to the host cell), or synthetic (not native to any cell). Suitable fusion partners include, but are not limited to: a) presentation structures, as defined below, which provide the candidate bioactive agents in a conformationally restricted or stable form; b) targeting sequences, defined below, which allow the localization of the candidate bioactive agent into a 20 subcellular or extracellular compartment, particularly a nuclear localization sequence (NLS); c) rescue sequences as defined below, which allow the purification or isolation of either the candidate bioactive agents or the nucleic acids encoding them; d) stability sequences, which confer stability or protection from degradation to the candidate bioactive agent or the nucleic acid encoding it, for example resistance to proteolytic degradation; e) dimerization sequences, to allow for peptide dimerization; f) reporter genes (preferably a labeling gene or a survival gene); or g) any combination of a), b), c), d), 25 e), or f) as well as linker sequences as needed.

In a preferred embodiment, the fusion partner is a presentation structure. By "presentation structure" or grammatical equivalents herein is meant a sequence, which, when fused to candidate bioactive 30 agents, causes the candidate agents to assume a conformationally restricted form. Proteins interact with each other largely through conformationally constrained domains. Although small peptides with freely rotating amino and carboxyl termini can have potent functions as is known in the art, the conversion of such peptide structures into pharmacologic agents is difficult due to the inability to predict side-chain positions for peptidomimetic synthesis. Therefore the presentation of peptides in 35 conformationally constrained structures will benefit both the later generation of pharmaceuticals and will also likely lead to higher affinity interactions of the peptide with the target protein. This fact has been recognized in the combinatorial library generation systems using biologically generated short

peptides in bacterial phage systems. A number of workers have constructed small domain molecules in which one might present randomized peptide structures.

5 While the candidate bioactive agents may be either nucleic acid or peptides, presentation structures are preferably used with peptide candidate agents. Thus, synthetic presentation structures, i.e. artificial polypeptides, are capable of presenting a randomized peptide as a conformationally-restricted domain. Generally such presentation structures comprise a first portion joined to the N-terminal end of the randomized peptide, and a second portion joined to the C-terminal end of the peptide; that is, the peptide is inserted into the presentation structure, although variations may be made, as outlined 10 below. To increase the functional isolation of the randomized expression product, the presentation structures are selected or designed to have minimal biologically activity when expressed in the target cell.

15 Preferred presentation structures maximize accessibility to the peptide by presenting it on an exterior loop. Accordingly, suitable presentation structures include, but are not limited to, minibody structures, loops on beta-sheet turns and coiled-coil stem structures in which residues not critical to structure are randomized, zinc-finger domains, cysteine-linked (disulfide) structures, transglutaminase linked structures, cyclic peptides, B-loop structures, helical barrels or bundles, leucine zipper motifs, etc.

20 In a preferred embodiment, the presentation structure is a coiled-coil structure, allowing the presentation of the randomized peptide on an exterior loop. See, for example, Myszka et al., Biochem. 33:2362-2373 (1994), hereby incorporated by reference). Using this system investigators have isolated peptides capable of high affinity interaction with the appropriate target. In general, coiled-coil structures allow for between 6 to 20 randomized positions.

25 A preferred coiled-coil presentation structure is as follows:
~~MGCAALESEVSALESEVASEVAALGRGDMP~~LAAVKS~~KLSAVKS~~KLASVKS~~KLAACGPP~~. The underlined regions represent a coiled-coil leucine zipper region defined previously (see Martin et al., EMBO J. 13(22):5303-5309 (1994), incorporated by reference). The bolded GRGDMP region 30 represents the loop structure and when appropriately replaced with randomized peptides (i.e. candidate bioactive agents, generally depicted herein as (X)_n, where X is an amino acid residue and n is an integer of at least 5 or 6) can be of variable length. The replacement of the bolded region is facilitated by encoding restriction endonuclease sites in the underlined regions, which allows the direct incorporation of randomized oligonucleotides at these positions. For example, a preferred 35 embodiment generates a Xhol site at the double underlined LE site and a HindIII site at the double-underlined KL site.

In a preferred embodiment, the presentation structure is a minibody structure. A "minibody" is essentially composed of a minimal antibody complementarity region. The minibody presentation structure generally provides two randomizing regions that in the folded protein are presented along a single face of the tertiary structure. See for example Bianchi et al., J. Mol. Biol. 236(2):649-59 (1994), and references cited therein, all of which are incorporated by reference). Investigators have shown this minimal domain is stable in solution and have used phage selection systems in combinatorial libraries to select minibodies with peptide regions exhibiting high affinity, $K_d = 10^{-7}$, for the pro-inflammatory cytokine IL-6.

A preferred minibody presentation structure is as follows:

~~MGRNSQATSGFTSHFYMEWVRGGEYIAASRHKHNKYTTEYSASVKGRYIVSRDTSQSILYLQKKKG
PP.~~ The bold, underline regions are the regions which may be randomized. The italicized phenylalanine must be invariant in the first randomizing region. The entire peptide is cloned in a three-oligonucleotide variation of the coiled-coil embodiment, thus allowing two different randomizing regions to be incorporated simultaneously. This embodiment utilizes non-palindromic BstXI sites on the termini.

In a preferred embodiment, the presentation structure is a sequence that contains generally two cysteine residues, such that a disulfide bond may be formed, resulting in a conformationally constrained sequence. This embodiment is particularly preferred when secretory targeting sequences are used. As will be appreciated by those in the art, any number of random sequences, with or without spacer or linking sequences, may be flanked with cysteine residues. In other embodiments, effective presentation structures may be generated by the random regions themselves. For example, the random regions may be "doped" with cysteine residues which, under the appropriate redox conditions, may result in highly crosslinked structured conformations, similar to a presentation structure.

Similarly, the randomization regions may be controlled to contain a certain number of residues to confer β -sheet or α -helical structures.

In a preferred embodiment, the fusion partner is a targeting sequence that targets the candidate bioactive agent to a particular subcellular location. As will be appreciated by those in the art, the localization of proteins within a cell is a simple method for increasing effective concentration and determining function. The concentration of a protein can also be simply increased by nature of the localization. Shuttling the proteins into the nucleus confines them to a smaller space thereby increasing concentration. While other targeting sequences such as targeting sequences to the Golgi, endoplasmic reticulum, nuclear membrane, mitochondria, secretory vesicles, lysosome, and cellular membrane may be used, a preferred embodiment uses targeting sequences to the nucleus, i.e. a nuclear localization signal (NLS).

Sally Alp

5 In a preferred embodiment, the targeting sequence is a nuclear localization signal (NLS). NLSs are generally short, positively charged (basic) domains that serve to direct the entire protein in which they occur to the cell's nucleus. Numerous NLS amino acid sequences have been reported including single basic NLS's such as that of the SV40 (monkey virus) large T Antigen (Pro Lys Lys Lys Arg Lys Val), Kalderon (1984), et al., Cell, 39:499-509; the human retinoic acid receptor- β nuclear localization signal (ARRRRP); NF κ B p50 (EEVQRKRQKL; Ghosh et al., Cell 62:1019 (1990); NF κ B p65 (EEKRKRTYE; Nolan et al., Cell 64:961 (1991); and others (see for example Boulikas, J. Cell. Biochem. 55(1):32-58 (1994), hereby incorporated by reference) and double basic NLS's exemplified by that of the Xenopus (African clawed toad) protein, nucleoplasmin (Ala Val Lys Arg Pro Ala Ala Thr 10 Lys Lys Ala Gly Gln Ala Lys Lys Lys Lys Leu Asp), Dingwall, et al., Cell, 30:449-458, 1982 and Dingwall, et al., J. Cell Biol., 107:641-849; 1988). Numerous localization studies have demonstrated that NLSs incorporated in synthetic peptides or grafted onto reporter proteins not normally targeted to the cell nucleus cause these peptides and reporter proteins to be concentrated in the nucleus. See, for example, Dingwall, and Laskey, Ann, Rev. Cell Biol., 2:367-390, 1986; Bonnerot, et al., Proc. Natl. 15 Acad. Sci. USA, 84:6795-6799, 1987; Galileo, et al., Proc. Natl. Acad. Sci. USA, 87:458-462, 1990.

20 In a preferred embodiment, the fusion partner is a rescue sequence. A rescue sequence is a sequence which may be used to purify or isolate either the candidate agent or the nucleic acid encoding it. Thus, for example, peptide rescue sequences include purification sequences such as the His₆ tag for use with Ni affinity columns and epitope tags for detection, immunoprecipitation or FACS (fluorescence-activated cell sorting). Suitable epitope tags include myc (for use with the commercially available 9E10 antibody), the BSP biotinylation target sequence of the bacterial enzyme BirA, flu tags, lacZ, and GST.

25 Alternatively, the rescue sequence may be a unique oligonucleotide sequence which serves as a probe target site to allow the quick and easy isolation of the retroviral construct, via PCR, related techniques, or hybridization.

30 In a preferred embodiment, the fusion partner is a stability sequence to confer stability to the candidate bioactive agent or the nucleic acid encoding it. Thus, for example, peptides may be stabilized by the incorporation of glycines after the initiation methionine (MG or MGG0), for protection of the peptide to ubiquitination as per Varshavsky's N-End Rule, thus conferring long half-life in the cytoplasm. Similarly, two prolines at the C-terminus impart peptides that are largely resistant to carboxypeptidase action. The presence of two glycines prior to the prolines impart both flexibility and 35 prevent structure initiating events in the di-proline to be propagated into the candidate peptide structure. Thus, preferred stability sequences are as follows: MG(X)_nGGPP, where X is any amino acid and n is an integer of at least four.

In one embodiment, the fusion partner is a dimerization sequence. A dimerization sequence allows the non-covalent association of one random peptide to another random peptide, with sufficient affinity to remain associated under normal physiological conditions. This effectively allows small libraries of random peptides (for example, 10^4) to become large libraries if two peptides per cell are generated which then dimerize, to form an effective library of 10^8 ($10^4 \times 10^4$). It also allows the formation of longer random peptides, if needed, or more structurally complex random peptide molecules. The dimers may be homo- or heterodimers.

Dimerization sequences may be a single sequence that self-aggregates, or two sequences, each of which is generated in a different retroviral construct. That is, nucleic acids encoding both a first random peptide with dimerization sequence 1, and a second random peptide with dimerization sequence 2, such that upon introduction into a cell and expression of the nucleic acid, dimerization sequence 1 associates with dimerization sequence 2 to form a new random peptide structure.

Suitable dimerization sequences will encompass a wide variety of sequences. Any number of protein-protein interaction sites are known. In addition, dimerization sequences may also be elucidated using standard methods such as the yeast two hybrid system, traditional biochemical affinity binding studies, or even using the present methods.

In a preferred embodiment, the fusion partner is a detection gene, preferably a labeling gene or a survival gene. That is, it is desirable to know that the candidate bioactive agent is a) present and b) being expressed. Thus, preferred embodiments utilize fusion constructs utilizing genes that allow the detection of cells that contain candidate bioactive agents, as is generally outlined in the Examples, and shown in Figure 10. Preferred detection genes include, but are not limited to, GFP, BFP, YFP, RFP, luciferase, and β -galactosidase. Preferred embodiments utilize detection genes that are different from the reporter genes used to determine whether the IL-4 inducible promoter is inhibited; that is, if a GFP reporter gene is used, preferably a non-GFP detection gene is used. This allows cell enrichment using FACS that can distinguish between cells containing candidate agents and those that do not, as well distinguishing cells containing candidate agents that do not inhibit the promoter and cells containing candidate agents that do inhibit the promoter.

In a preferred embodiment, as for the other constructs outlined herein, when a detection gene fusion partner is used with nucleic acid encoding a peptide candidate agent (which may also include other fusion partners as described herein), the two nucleic acids are fused together in such a way as to only require a single promoter, i.e. using either an IRES site or a protease cleavage site such as 2a. A preferred embodiment is depicted in Figure 10B.

Only PCT
The fusion partners may be placed anywhere (i.e. N-terminal, C-terminal, internal) in the structure as the biology and activity permits.

In a preferred embodiment, the fusion partner includes a linker or tethering sequence, as generally described in PCT US 97/01019, that can allow the candidate agents to interact with potential targets unhindered. For example, when the candidate bioactive agent is a peptide, useful linkers include glycine-serine polymers (including, for example, $(GS)_n$, $(GSGGS)_n$, and $(GGGS)_n$, where n is an integer of at least one), glycine-alanine polymers, alanine-serine polymers, and other flexible linkers such as the tether for the shaker potassium channel, and a large variety of other flexible linkers, as will be appreciated by those in the art. Glycine-serine polymers are preferred since both of these amino acids are relatively unstructured, and therefore may be able to serve as a neutral tether between components. Secondly, serine is hydrophilic and therefore able to solubilize what could be a globular glycine chain. Third, similar chains have been shown to be effective in joining subunits of recombinant proteins such as single chain antibodies.

15 In addition, the fusion partners, including presentation structures, may be modified, randomized, and/or matured to alter the presentation orientation of the randomized expression product. For example, determinants at the base of the loop may be modified to slightly modify the internal loop peptide tertiary structure, which maintaining the randomized amino acid sequence.

20 In a preferred embodiment, combinations of fusion partners are used. Thus, for example, any number of combinations of presentation structures, targeting sequences, rescue sequences, and stability sequences may be used, with or without linker sequences.

25 Thus, candidate agents can include these components, and may then be used to generate a library of fragments, each containing a different random nucleotide sequence that may encode a different peptide. The ligation products are then transformed into bacteria, such as *E. coli*, and DNA is prepared from the resulting library, as is generally outlined in Kitamura, PNAS USA 92:9146-9150 (1995), hereby expressly incorporated by reference.

30 Delivery of the library DNA into a retroviral packaging system results in conversion to infectious virus. Suitable retroviral packaging system cell lines include, but are not limited to, the Bing and BOSC23 cell lines described in WO 94/19478; Soneoka et al., Nucleic Acid Res. 23(4):628 (1995); Finer et al., Blood 83:43 (1994); Pheonix packaging lines such as PhiNX-eco and PhiNX-ampho, described below; 35 292T + gag-pol and retrovirus envelope; PA317; and cell lines outlined in Markowitz et al., Virology 167:400 (1988), Markowitz et al., J. Virol. 62:1120 (1988), Li et al., PNAS USA 93:11658 (1996), Kinsella et al., Human Gene Therapy 7:1405 (1996), all of which are incorporated by reference.

Preferred systems include PhiNX-eco and PhiNX-ampho or similar cell lines, disclosed in PCT US97/01019.

In general, the candidate agents are added to the cells under reaction conditions that favor agent-target interactions. Generally, this will be physiological conditions. Incubations may be performed at any temperature which facilitates optimal activity, typically between 4 and 40°C. Incubation periods are selected for optimum activity, but may also be optimized to facilitate rapid high through put screening. Typically between 0.1 and 1 hour will be sufficient. Excess reagent is generally removed or washed away.

10

A variety of other reagents may be included in the assays. These include reagents like salts, neutral proteins, e.g. albumin, detergents, etc which may be used to facilitate optimal protein-protein binding and/or reduce non-specific or background interactions. Also reagents that otherwise improve the efficiency of the assay, such as protease inhibitors, nuclease inhibitors, anti-microbial agents, etc., may be used. The mixture of components may be added in any order that provides for the requisite binding.

15

Once the candidate agents have been introduced or combined with the cells containing the fusion constructs, the IL-4 inducible ϵ promoter is induced. Alternatively, the promoter is induced prior to the addition of the candidate bioactive agents, or simultaneously. This is generally done as is known in the art, and involves the addition of IL-4 or IL-13 to the cells at a concentration of not less than 5 units/ml with 200 units/ml being most preferred. Addition of IL-4 or IL-13 is usually 24-48 hours after the bioactive agents are added.

20

25 The presence or absence of the reporter gene is then detected. This may be done in a number of ways, as will be appreciated by those in the art, and will depend in part on the reporter gene. For example, cells expressing a label reporter gene, such as GFP, can be distinguished from those not expressing the gene, and preferably sorted (enriched by FACS) on this basis. Similarly, cells expressing the death gene will die, leaving only cells that have inhibited promotion of the expression of the gene, etc. In general, the cells that express the reporter gene (i.e. non-inhibited IL-4 inducible ϵ promoter) and separated from those that do not (i.e. the IL-4 inducible ϵ promoter was inhibited). This may be done using FACS, lysis selection using complements, cell cloning, scanning by a Fluorimager, growth under drug resistance, enhanced growth, etc.

30

35 In a preferred embodiment, for example when the reporter gene is a death gene, sorting of cells containing bioactive agents that inhibit the IL-4 inducible ϵ promoter (and thus do not turn on the death gene) from those cells that contain candidate agents that do not inhibit the promoter is simple: only those surviving cells contain such an agent.

In a preferred embodiment, the presence or absence of the reporter gene is determined using a fluorescent-activated cell sorter (FACS). In general, the expression of the reporter gene comprising a label (or allowing the use of a label) is optimized to allow for efficient enrichment by FACS. Thus, for example, in general, 10 to 1000 fluores per sorting event are needed; i.e. per cell, with from about 100 to 1000 being preferred, and from 500 to 1000 being especially preferred. This can be accomplished by amplifying the signal per reporter gene, i.e. have each second label comprise multiple fluores, or by having a high density of reporter genes per cell; or a combination of both.

5

In a preferred embodiment, the cells are sorted at very high speeds, for example greater than about 5,000 sorting events per sec, with greater than about 10,000 sorting events per sec being preferred, and greater than about 25,000 sorting events per second being particularly preferred, with speeds of greater than about 50,000 to 100,000 being especially preferred. The use of multiple laser paths allows sort accuracy of 1 in 10^6 with better than 70% accuracy.

10

15

The sorting results in a population of cells containing the reporter protein (i.e. the promoter was not inhibited) and at least one population of cells without the reporter protein (i.e. the promoter was inhibited). The absence of the reporter protein is indicative that at least one candidate bioactive agent is a bioactive agent that inhibits the IL-4 inducible ϵ promoter.

20

25

In addition to screening methods utilizing the reporter constructs described above, the invention also provides methods for screening candidate agents for the ability to modulate IgE production. By "modulating IgE production" herein is meant either an increase or a decrease in IgE production, as quantified by the amount of IgE protein made. In this embodiment, cells that have already switched to the ϵ heavy chain region can no longer be blocked at the earlier phase of IgE production. This is especially important for memory B cells that maintain their capacity to secrete IgE and are long lived. Thus, in this embodiment, candidate agents are screened to identify compounds that can block IgE at the level of ϵ heavy chain transcription, translation, assembly and trafficking, to prevent the terminal stages of IgE production. In this embodiment, a candidate bioactive agent is combined with a cell capable of expressing IgE, preferably surface IgE. Preferred cells include, but are not limited to, cells 30 that produce surface IgE such as the U266 cell line (Lagging, et al., "Distribution of Plasma Cell Markers and Intracellular IgE in Cell Line U266," *Immunology Letters* 49:71 (1996)).

35

The candidate agent and the cells are combined, as outlined above, and the cells screened for alterations in the amount of IgE produced, as compared to the amount produced in the absence of the candidate bioactive agent. This may be done using standard IgE labeling techniques, including, but not limited to, the use of anti-IgE antibodies, that may be either directly or indirectly labeled, for example through the use of fluorescent anti-IgE antibodies or fluorescent secondary antibodies, and through the use of IgE fusion proteins, as outlined below.

In a preferred embodiment, the amount of IgE produced is determined through the use of IgE fusion proteins; that is, the IgE is produced as a fusion protein comprising the IgE protein, specifically at least the ϵ heavy chain, and a detectable protein such as is generally outlined above for label reporter genes. In a preferred embodiment, gene "knock in" cell lines are produced, as outlined above and shown in the Figures. In this embodiment, a first label gene, such as the gene for green fluorescent protein (GFP), is fused to the secretory exon of IgE to label secretory IgE heavy chains green. In a preferred embodiment, a second label gene, such as the gene for blue fluorescent protein (BFP), is attached to the M2 exon to label membrane IgE heavy chains blue. This is preferred as it allows discrimination between mRNA processing and translation of secretory versus membrane ϵ -heavy chain transcripts. Suitable label genes for this embodiment include, but are not limited to, GFP, BFP, YFP and RFP.

Accordingly, the present invention provides cell lines that produce fusion proteins comprising IgE (either secreted or membrane bound) fused to a label protein, preferably a fluorescent protein.

In yet another preferred embodiment, the invention provides methods of identifying proteins that bind to all or part of the switch ϵ region (Figure 2B). The general idea is to use a "one hybrid" system to identify proteins that bind to all or part of the switch ϵ region. To this end, the present invention provides compositions comprising a test vector and a reporter vector, and cells containing these vectors. These cells may be yeast, such as YM4271 or any yeast cell lines that reporter constructs can be inserted into.

By "vector" or "episome" herein is meant a replicon used for the transformation of host cells. The vectors may be either self-replicating extrachromosomal vectors ("plasmids") or vectors which integrate into a host genome. A preferred embodiment utilizes retroviral vectors, as is more fully described below.

Suitable vectors will depend on the host cells used. For use of the system in yeast, suitable vectors are known in the art and include, but are not limited to, pHisi-1 and pLacZi (Clonetech Cat #K1603-1) (Li, et al., "Isolation of ORC6, A Component of the Yeast Origin of Recognition Complex By a One-Hybrid System," *Science* 262:1870-1873 (1993); Liu, et al. "Identifying DNA-Binding Sites and Analyzing DNA-Binding Domains Using a Yeast Selection System," In: *Methods: A Companion to Methods in Enzymology* 5:125-137 (1993), Luo, et al., "Cloning and Analysis of DNA-Binding Proteins By Yeast One-Hybrid and One-Two-Hybrid Systems," *Biotechniques* 20:564-568 (1996), and Strubin, et al., "OBF-1, A Novel B Cell-Specific Coactivator That Stimulates Immunoglobulin Promoter Activity Through Association with Octamer-Binding Proteins," *Cell* 80:497-506 (1995)). Yeast expression systems are well known in the art, and include expression vectors for *Saccharomyces cerevisiae*, *Candida albicans* and *C. maltosa*, *Hansenula polymorpha*, *Kluyveromyces fragilis* and *K. lactis*, *Pichia*

guillerimondii and *P. pastoris*, *Schizosaccharomyces pombe*, and *Yarrowia lipolytica*. Preferred promoter sequences for expression in yeast include the inducible GAL1,10 promoter, the promoters from alcohol dehydrogenase, enolase, glucokinase, glucose-6-phosphate isomerase, glyceraldehyde-3-phosphate-dehydrogenase, hexokinase, phosphofructokinase, 3-phosphoglycerate mutase, pyruvate kinase, and the acid phosphatase gene. Yeast selectable markers include ADE2, HIS4, LEU2, TRP1, and ALG7, which confers resistance to tunicamycin; the neomycin phosphotransferase gene, which confers resistance to G418; and the CUP1 gene, which allows yeast to grow in the presence of copper ions.

- 10 For non-retroviral mammalian cell embodiments, suitable vectors are derived from any number of known vectors, including, but not limited to, pCEP4 (Invitrogen), pCI-NEO (Promega), and pBI-EGFP (Clontech). Basically, any mammalian expression vectors with strong promoters such as CMV can be used to construct test vectors.
- 15 In a preferred embodiment, one or more retroviral vectors are used. Currently, the most efficient gene transfer methodologies harness the capacity of engineered viruses, such as retroviruses, to bypass natural cellular barriers to exogenous nucleic acid uptake. The use of recombinant retroviruses was pioneered by Richard Mulligan and David Baltimore with the Psi-2 lines and analogous retrovirus packaging systems, based on NIH 3T3 cells (see Mann et al., Cell 33:153-159 (1993), hereby incorporated by reference). Such helper-defective packaging lines are capable of producing all the necessary trans proteins -gag, pol, and env- that are required for packaging, processing, reverse transcription, and integration of recombinant genomes. Those RNA molecules that have in cis the ψ packaging signal are packaged into maturing virions.
- 20 25 Retroviruses are preferred for a number of reasons. First, their derivation is easy. Second, unlike Adenovirus-mediated gene delivery, expression from retroviruses is long-term (adenoviruses do not integrate). Adeno-associated viruses have limited space for genes and regulatory units and there is some controversy as to their ability to integrate. Retroviruses therefore offer the best current compromise in terms of long-term expression, genomic flexibility, and stable integration, among other features. The main advantage of retroviruses is that their integration into the host genome allows for their stable transmission through cell division. This ensures that in cell types which undergo multiple independent maturation steps, such as hematopoietic cell progression, the retrovirus construct will remain resident and continue to express. In addition, transfection efficiencies can be extremely high, thus obviating the need for selection genes in some cases.
- 30 35 A particularly well suited retroviral transfection system is described in Mann et al., *supra*; Pear et al., PNAS USA 90(18):8392-6 (1993); Kitamura et al., PNAS USA 92:9146-9150 (1995); Kinsella et al., Human Gene Therapy 7:1405-1413; Hofmann et al., PNAS USA 93:5185-5190; Choate et al., Human

Gene Therapy 7:2247 (1996); WO 94/19478; PCT US97/01019, and references cited therein, all of which are incorporated by reference.

5 Any number of suitable retroviral vectors may be used. Preferred retroviral vectors include a vector based on the murine stem cell virus (MSCV) (see Hawley et al., Gene Therapy 1:136 (1994)) and a modified MFG virus (Rivere et al., Genetics 92:6733 (1995)), and pBABE (see PCT US97/01019, incorporated by reference). Particularly preferred vectors are shown in Figure 11.

10 As for the other vectors, the retroviral vectors may include inducible and constitutive promoters. Constitutive promoters are preferred for the bait and test vectors, and include, but are not limited to, CMV, SV40, S α , RSV, and TK. Similarly, the reporter vector promoter is associated with at least one 15 copy of an operator, as outlined herein.

15 In addition, it is possible to configure a retroviral vector to allow expression of bait genes or test genes after integration of a bait or test vector in target cells. For example, Tet-inducible retroviruses can be used to express bait or test genes (Hoffman et al., PNAS USA 93:5185 (1996)). Expression of this vector in cells is virtually undetectable in the presence of tetracycline or other active analogs. However, in the absence of Tet, expression is turned on to maximum within 48 hours after induction, with uniform increased expression of the whole population of cells that harbor the inducible retrovirus, 20 indicating that expression is regulated uniformly within the infected cell population. A similar, related system uses a mutated Tet DNA-binding domain such that it bound DNA in the presence of Tet, and was removed in the absence of Tet. Either of these systems is suitable.

25 Generally, these expression vectors include transcriptional and translational regulatory nucleic acid operably linked to nucleic acids which are to be expressed. "Operably linked" in this context means that the transcriptional and translational regulatory nucleic acid is positioned relative to any coding sequences in such a manner that transcription is initiated. Generally, this will mean that the promoter and transcriptional initiation or start sequences are positioned 5' to the coding region. The 30 transcriptional and translational regulatory nucleic acid will generally be appropriate to the host cell used, as will be appreciated by those in the art. Numerous types of appropriate expression vectors, and suitable regulatory sequences, are known in the art for a variety of host cells.

35 In general, the transcriptional and translational regulatory sequences may include, but are not limited to, promoter sequences, ribosomal binding sites, transcriptional start and stop sequences, translational start and stop sequences, and enhancer or activator sequences. In a preferred embodiment, the regulatory sequences include a promoter and transcriptional start and stop sequences.

Promoter sequences encode either constitutive or inducible promoters. The promoters may be either naturally occurring promoters, hybrid or synthetic promoters. Hybrid promoters, which combine elements of more than one promoter, are also known in the art, and are useful in the present invention.

5

In general, the vectors of the present invention utilize two different types of promoters.

In a preferred embodiment, the promoters on the bait and test vectors are constitutive, and drive the expression of the fusion proteins and selection genes, if applicable, at a high level. However, it is possible to utilize inducible promoters for the fusion constructs and selection genes, if necessary.

10

The test vector comprises a selection gene. Selection genes allow the selection of transformed host cells containing the vector, and particularly in the case of mammalian cells, ensures the stability of the vector, since cells which do not contain the vector will generally die. Selection genes are well known in the art and will vary with the host cell used. Suitable selection genes include, but are not limited to, neomycin, blastocidin, bleomycin, puromycin, hygromycin, and other drug resistance genes, as well as genes required for growth on certain media, including, but not limited to, His and Lev or His and Trp.

15

In some cases, for example when using retroviral vectors, the requirement for selection genes is lessened due to the high transformation efficiencies which can be achieved. Accordingly, selection genes need not be used in retroviral constructs, although they can be. In addition, when retroviral vectors are used, the test vectors may also contain detectable genes as are described herein rather than selection genes; it may be desirable to verify that the vector is present in the cell, but not require selective pressure for maintenance.

20

In addition to the selection gene, the test vector comprises a fusion gene comprising a first sequence encoding a transcriptional activation domain, and a second sequence encoding a test protein. By "fusion gene" or "fusion construct" herein is meant nucleic acid that comprises at least two functionally distinct sequences; i.e. generally sequences from two different genes. As will be appreciated by those in the art, in some embodiments the sequences described herein may be DNA, for example when extrachromosomal plasmids are the vectors, or RNA, for example when retroviral vectors are used.

25

Generally, the sequences are directly linked together without any linking sequences, although in some embodiments linkers such as restriction endonuclease cloning sites or linkers encoding flexible amino acids such as glycine and serine linkers such as are known in the art are used. In a preferred embodiment, the first fusion gene comprises a first sequence encoding a transcriptional activation domain. By "transcriptional activator domain" herein is meant a proteinaceous domain which is able to activate transcription.

30

Suitable transcription activator domains include, but are not limited to, transcriptional activator domains from GAL4 (amino acids 1-147; see Fields et al., *Nature* 340:245 (1989), and Gill et al.,

35

PNAS USA 87:2127 (1990)), GCN4 (from *S. cerevisiae*, Hope et al., Cell 46:885 (1986)), ARD1 (from *S. cerevisiae*, Thukral et al., Mol. Cell. Biol. 9:2360 (1989)), the human estrogen receptor (Kumar et al., Cell 51:941 (1987)), VP16 (Triezenberg et al., Genes Dev. 2(6):718-729 (1988)), and B42 (Gyuris et al, Cell 1993), and NF- κ B p65, and derivatives thereof which are functionally similar.

5

The fusion nucleic acid also includes a test nucleic acid, encoding a test protein. By "test protein" herein is meant a candidate protein which is to be tested for interaction with a bait protein. Protein in this context means proteins, oligopeptides, and peptides, i.e. at least two amino acids attached. In a preferred embodiment, the test protein sequence is one of a library of test protein sequences; that is, a library of test proteins is tested for binding to one or more bait proteins. The test protein sequences can be derived from genomic DNA, cDNA or can be random sequences. Alternatively, specific classes of test proteins may be tested. The library of test proteins or sequences encoding test proteins are incorporated into a library of test vectors, each or most containing a different test protein sequence.

10

In a preferred embodiment, the test protein sequences are derived from genomic DNA sequences. Generally, as will be appreciated by those in the art, genomic digests are cloned into test vectors. The genomic library may be a complete library, or it may be fractionated or enriched as will be appreciated by those in the art.

15

In a preferred embodiment, the test protein sequences are derived from cDNA libraries. A cDNA library from any number of different cells may be used, and cloned into test vectors. As above, the cDNA library may be a complete library, or it may be fractionated or enriched in a number of ways.

20

In a preferred embodiment, the test protein sequences are random sequences. Generally, these will be generated from chemically synthesized oligonucleotides. Generally, random test proteins range in size from about 2 amino acids to about 100 amino acids, with from about 10 to about 50 amino acids being preferred. Fully random or "biased" random proteins may be used; that is, some positions within the sequence are either held constant or are selected from a limited number of possibilities. For

25

example, in a preferred embodiment, the nucleotides or amino acid residues are randomized within a defined class, for example, of hydrophobic amino acids, hydrophilic residues, sterically biased (either small or large) residues, towards the creation of cysteines, for cross-linking, prolines for SH-3 domains, serines, threonines, tyrosines or histidines for phosphorylation sites, etc., for zinc fingers, SH-2 domains, stem loop structures, or to purines, or to reduce the chance of creation of a stop codon, etc.

30

The compositions of the invention also include reporter vectors. Generally, the test and reporter vectors are distinct, although as will be appreciated by those in the art, one or two independent vectors

may be used. The reporter vectors comprise a first detectable or reporter gene and all or part of the switch ϵ sequence, which functions as an operator site. That is, upon binding of a test protein to the switch ϵ sequence (i.e. a protein-nucleic acid interaction), the transcriptional activator domain of the fusion protein will activate transcription and cause expression of the selectable or detectable gene(s).

5 Thus, in this embodiment, the test protein functions essentially as a candidate agent.

In a preferred embodiment, the compositions are introduced into host cells to screen for protein-nucleic acid interactions. By "introduced into" or grammatical equivalents herein is meant that the nucleic acids enter the cells in a manner suitable for subsequent expression of the nucleic acid. The 10 method of introduction is largely dictated by the targeted cell type and the composition of the vector. Exemplary methods include CaPO_4 precipitation, liposome fusion, lipofectin®, electroporation, viral infection, etc. The vectors may stably integrate into the genome of the host cell (for example, with retroviral introduction for mammalian cells, outlined herein), or may exist either transiently or stably in the cytoplasm (i.e. through the use of traditional plasmids, utilizing standard regulatory sequences, 15 selection markers, etc.).

The vectors can be introduced simultaneously, or sequentially in any order. In a preferred embodiment, host cells containing the reporter construct are generated first, and preferably the reporter vector is integrated into the genome of the host cell, for example, using a retroviral reporter 20 vector. Once the components of the system are in the host cell, the cell is subjected to conditions under which the selectable markers and fusion proteins are expressed. If a test protein has sufficient affinity to the switch ϵ region to activate transcription, the detectable protein is produced, and cells containing these proteins will survive drug selection and can be detected as outlined above. The 25 detectable protein will be produced at a measurably higher level than in the absence of a protein-nucleic acid interaction. Thus the determination of a protein-nucleic acid interaction is generally done on the basis of the presence or absence of the detectable gene(s).

In a preferred embodiment, once a cell with an altered phenotype is detected, the cell is isolated from the plurality which do not have altered phenotypes. This may be done in any number of ways, as is 30 known in the art, and will in some instances depend on the assay or screen. Suitable isolation techniques include, but are not limited to, drug selection, FACS, lysis selection using complement, cell cloning, scanning by Fluorimager, expression of a "survival" protein, induced expression of a cell surface protein or other molecule that can be rendered fluorescent or taggable for physical isolation; expression of an enzyme that changes a non-fluorescent molecule to a fluorescent one; overgrowth 35 against a background of no or slow growth; death of cells and isolation of DNA or other cell vitality indicator dyes; changes in fluorescent characteristics, etc. The preferred isolation techniques are drug selection and FACS based on the expression of the detectable gene, with a preferred embodiment utilizing both simultaneously.

Once a cell with a protein-nucleic acid interaction is detected and isolated, it is generally desirable to identify the test protein. In a preferred embodiment, the test protein nucleic acid and/or the test protein is isolated from the positive cell. This may be done in a number of ways. In a preferred embodiment, primers complementary to DNA regions common to the vector, or to specific components of the library such as a rescue sequence, are used to "rescue" the unique test sequence. Alternatively, the test protein is isolated using a rescue sequence. Thus, for example, rescue sequences comprising epitope tags or purification sequences may be used to pull out the test protein, using immunoprecipitation or affinity columns. Alternatively, the test protein may be detected using mass spectroscopy.

10

Once a bioactive agent is identified, a number of things may be done. In a preferred embodiment, the characterization of the bioactive agent is done. This will proceed as will be appreciated by those in the art, and generally includes an analysis of the structure, identity, binding affinity and function of the agent. Depending on the type of agent, this may proceed in a number of ways. In a preferred embodiment, for example when the candidate agents have been introduced intracellularly using nucleic acid constructs, the candidate nucleic acid and/or the bioactive agent is isolated from the cells. This may be done in a number of ways. In a preferred embodiment, primers complementary to DNA regions common to the retroviral constructs, or to specific components of the library such as a rescue sequence, defined above, are used to "rescue" the unique random sequence. Alternatively, the bioactive agent is isolated using a rescue sequence. Thus, for example, rescue sequences comprising epitope tags or purification sequences may be used to pull out the bioactive agent, using immunoprecipitation or affinity columns. Alternatively, the peptide may be detected using mass spectroscopy.

20

Once rescued, the sequence of the bioactive agent and/or bioactive nucleic acid is determined. Similarly, candidate agents from other chemical classes can be identified and characterized, for example through the use of mass spectroscopy. This information can then be used in a number of ways.

25

In a preferred embodiment, the bioactive agent is resynthesized and reintroduced into the target cells, to verify the effect. This may be done using retroviruses, or alternatively using fusions to the HIV-1 Tat protein, and analogs and related proteins, which allows very high uptake into target cells. See for example, Fawell et al., PNAS USA 91:664 (1994); Frankel et al., Cell 55:1189 (1988); Savion et al., J. Biol. Chem. 256:1149 (1981); Derossi et al., J. Biol. Chem. 269:10444 (1994); and Baldin et al., EMBO J. 9:1511 (1990), all of which are incorporated by reference. Other techniques known in the art may be used as well.

30

35

In a preferred embodiment, the sequence of a bioactive agent is used to generate more candidate bioactive agents. For example, the sequence of the bioactive agent may be the basis of a second round of (biased) randomization, to develop bioactive agents with increased or altered activities.

Alternatively, the second round of randomization may change the affinity of the bioactive agent.

5 Furthermore, it may be desirable to put the identified random region of the bioactive agent into other presentation structures, or to alter the sequence of the constant region of the presentation structure, to alter the conformation/shape of the bioactive agent. It may also be desirable to "walk" around a potential binding site, in a manner similar to the mutagenesis of a binding pocket, by keeping one end of the ligand region constant and randomizing the other end to shift the binding of the peptide around.

10 Once identified and the biological activity is confirmed, the bioactive agent may be formulated. The compounds having the desired pharmacological activity may be administered in a physiologically acceptable carrier to a host, as previously described. The agents may be administered in a variety of ways, orally, parenterally e.g., subcutaneously, intraperitoneally, intravascularly, etc. Depending upon 15 the manner of introduction, the compounds may be formulated in a variety of ways. The concentration of therapeutically active compound in the formulation may vary from about 0.1-100 wt.%.

The pharmaceutical compositions can be prepared in various forms, such as granules, tablets, pills, suppositories, capsules, suspensions, salves, lotions and the like. Pharmaceutical grade organic or 20 inorganic carriers and/or diluents suitable for oral and topical use can be used to make up compositions containing the therapeutically-active compounds. Diluents known to the art include aqueous media, vegetable and animal oils and fats. Stabilizing agents, wetting and emulsifying agents, salts for varying the osmotic pressure or buffers for securing an adequate pH value, and skin penetration enhancers can be used as auxiliary agents.

25 The following examples serve to more fully describe the manner of using the above-described invention, as well as to set forth the best modes contemplated for carrying out various aspects of the invention. It is understood that these examples in no way serve to limit the true scope of this invention, but rather are presented for illustrative purposes. All references cited herein are incorporated by 30 reference in their entirety.

EXAMPLES

Example 1

Construction of ε germline GFP/BFP knock-in cell lines

35 Three different IgM⁺, EBV⁺ human B cells lines (CA-46, MC116, DND39, Figure 4) that produce ε germline transcripts in the presence of IL-4 will be transfected with a germline ε GFP or BFP knock-in construct (Figures 5B and 5C) and induced with IL-4. The cells will then be sorted by FACS for the

appropriate reporter expression, GFP or BFP. Background (i.e. random integration) should be low since the construct must integrate downstream of an IL-4 inducible region in order to be activated. Homologous recombination of the reporter construct will be confirmed in fluorescent clones by genomic PCR using primers located within and immediately flanking the construct. For double 5 knockouts, both GFP and BFP constructs will be transfected and cells sorted for expression of both reporters.

It is possible that activation with IL-4 to identify homologous recombined clones will result in events 10 that move beyond the first phase of ϵ switching, thus making the clones unusable for a screen identifying blockers of this first step. For this case, we have designed a more traditional construct containing an SV40 promoter-driven neomycin resistance gene which is flanked by loxP sites and inserted in the intron between the first and second ϵ constant coding exons (Figure 5D). In addition, attached at the 3' end of the long arm is a BFP reporter gene driven by a constitutive promoter. B cell clones transfected with this construct will be selected for integration by culturing them in the presence 15 of G418. The surviving cells lacking BFP will be sorted by FACS (the BFP at the 3' end will be preferentially deleted during the homologous recombination event). The remaining clones will be assessed for homologous recombination by PCR. Clones containing homologous recombined constructs will be exposed to the *cre* recombinase protein to mediate excision of the SV40 promoter/neomycin resistance gene in order to eliminate promoter interference and potential ϵ 20 promoter shutdown. Excision of the SV40 promoter/neomycin resistance gene fragment will be verified by subdividing clones into parent and daughter pools and re-selecting the latter pool in G418. The parental cells corresponding to G418 sensitive daughter cells will be subdivided again and tested for IL-4 inducible GFP expression. Parental stocks of the most inducible clones will be used for 25 subsequent peptide screening. Production of the knock-in cell line using this approach would provide a continuous source of IL-4 inducible cells and would circumvent any down-regulation associated with IL-4 pre-treatment.

Example 2

Creation and screening of candidate bioactive agents in knock-in cell lines

30 A candidate bioactive agent library, in this case a peptide library, will be packaged into infectious viral particles as outlined below. A preferred library is a mixture of random peptide sequences with and without a nuclear localization sequence (NLS) upstream of a reporter gene to identify infected cells and relative peptide expression (see Figure 6).

35 Each screen will start with production of the primary retrovirus peptide library, as is generally shown in Figure 7. This is generally done as outlined in PCT US97/01019 and PCT US97/01048, both of which are expressly incorporated by reference. In general, this is done as follows. On day 1, the Phoenix

cells are seeded in 10 cm plates at 5 X 10⁶ cells in 6 ml (DMEM + 10% FBS + Pen/Strep) per plate the day before transfection. Day 2: allow all reagents to reach room temperature 30 min. before starting. Add 50 mM chloroquine at 8 μ l/plate (50 μ M final) before preparing the transfection solution. Mix CaPO₄ reagents in 15ml polypropylene tube: per plate: 10 μ g DNA, 122 μ l 2M CaCl₂, 876 μ l H₂O, 5 1.0ml 2X HBS. Add 2X HBS and depress the expulsion button completely to bubble air through the mix for 10 secs. Immediately add mixture gently dropwise to plate. Incubate 3-8 hours. Remove medium and replace with 6.0 ml DMEM-medium. Day 3: Change medium again to 6.0 mls of medium optimal for the cells to be infected. Move to 32°C either in the morning or afternoon depending on the Phoenix cell confluence and whether you will infect at 48 or 72 hrs after transfection. Day 4 or 5: 10 Collect virus supernatant from transfected plates (6.0 ml) into 50 ml tubes and add protamine sulfate to a final concentration of 5 μ g/ml. Pass through a 0.45 μ m filter. Count target cells and distribute 10⁷ cells per 10 cm plate transfected to 50 ml tubes and pellet 5 min. Resuspend each pellet of target cells in virus supernatant and transfer to a 6 well plate at 1.0-1.2 ml per well. Seal plate with parafilm and centrifuge at RT for 30-90 min. at 2500 RPM. Remove parafilm and incubate plate over night at 37°C. 15 Day 5: Collect and pellet each well of target cells. Resuspend in 3 ml medium and transfer back to the same 6well plate. Infection can be repeated by refeeding the Phoenix cells with 6ml fresh medium and reinfecting the same cells again up to 3 times to increase % of cells infected (for instance at 48, 56, and 72 hours). Day 7 or Day 8: At 48 to 72 hrs. post infection, target cells are ready to analyze for expression. 20 This primary library will be used to infect at least 10⁹ knock-in cells. After infection, the cells will be stimulated with IL-4 and two days later, peptide-containing cells (identified by the fluorescent reporter) that are negative for the knock-in reporter (i.e. where there is ϵ promoter inhibition) will be sorted by FACS. This enriched, knock-in reporter negative population will be subjected to RT-PCR to amplify 25 the integrated peptide sequences. The PCR material will be used to construct a new "enriched" retrovirus peptide library to initiate the next screening round.

It will take approximately 5-7 rounds of enrichment to identify individual sequences capable of inhibiting the germline ϵ promoter, as outlined below using an iterative screening equation.

30

$$R = \frac{V}{\epsilon^p + (Q + \sum_{i=0}^{\infty} \beta (1 + \epsilon)^p) + v}$$

The above equation mathematically models screening efficiency and provides a guideline for monitoring enrichment for inhibitory peptides. R = ratio of true positive cells over the total number of

5 cells screened per round of selection; L = frequency of true positive cells (ie. # of cells expressing peptide inhibitors of IgE switch/synthesis); g = frequency of non-heritable false-positive cells (ie. # of cells in which IgE switch/synthesis is inhibited due to stimulation/screening inefficiencies, but are IgE positive in subsequent selection rounds); D = number of rounds of selection/enrichment applied to library screen; Q = initial frequency of cells with an heritable false-positive phenotype (ie. dominant-negative somatic mutation in cells that prevent IgE switch/synthesis); \$ = frequency of false-positives incurred by or during the selection/enrichment process.

10 Since we amplify enriched peptides by RT-PCR after each selection round, the equation can be simplified to

$$R = \frac{v}{e^p + Q + v}$$

15 By plugging in empirically-derived or estimated values for the variables, an estimate of how many selection rounds must be applied to a library before enrichment for IgE inhibitory peptide becomes apparent.

20 For the purposes of our screens, we engineer and select reporter cell lines in which the values of and Q are low to minimize the number of screening rounds necessary to observe rare positive peptide "hits".

25 For example, IL-4 treatment upregulates the IgE switch reporter in 97% of cells, therefore $g = 0.03$. Of the uninduced cells, a second round of stimulation indicates that less than .01% of the starting population contain heritable false positives, therefore $Q < 0.0001$. A conservative estimate of IgE inhibitory peptides in the starting population is $1/10^8$, therefore $v = 10^{-8}$. Solving the equation for the number of selection rounds required to enrich to 50% true positive hits...

$$0.5 = \frac{10^{-8}}{(0.03)^p + 10^{-3} + 10^{-8}} \rightarrow p = 5 \text{ rounds}$$

25 The most important factor that influences the number of enrichment rounds necessary to identify individual peptide hits is the ratio between the real positive peptide hits in the original library and the heritable false positives. The frequency of real positive peptide hits is dependent upon the qualitative ability of the peptide to access and, in the correct conformation, bind to regulatory domains on proteins in the pathway of interest. Thus, preferably, multiple scaffolding structures are used for presentation of random peptide surfaces and also different localization sequences fused to those peptide

structures. Enrichment of real positive peptides becomes less efficient with false positive rates above 2%. For this reason, great emphasis is placed on developing robust reporter constructs and cell lines.

5 Uneven RT-PCR amplification may decrease overall amplification of real peptides hits from one round to another. This is overcome by additional rounds of library enrichment and is why RT-PCR amplification is carefully monitored after each round of screening.

Example 3

10 Screening for inhibitors of IgE secretion in cells that have already switched

After B cells have switched to production of IgE, there are several factors that determine when they will secrete IgE. By screening for peptide inhibitors of surface IgE expression, proteins that regulate IgE transcription, translation, assembly and trafficking may be identified.

15 The IgE⁺ cell line, U266, expresses IgE on the surface and also secretes IgE. Antibodies against surface IgE heavy and light chains have been obtained and both are used to fluorescently mark IgE positive cells. The U266 line is consistently greater than 98.5% positive for membrane IgE.

20 Peptide library screening and target identification: The peptide library and enrichment protocols identical to those described in Example 2. As well, peptide hit validation and corresponding target protein identification will be performed as described in Example 2.

25 Development of an ε-heavy chain GFP/BFP knock-in cell line derivative of U266: The cytoplasmic tail of the ε-heavy chain in U266 cells will be engineered by homologous recombination to encode a GFP/BFP reporter as shown in Figure 8. This will produce a cell line that is fluorescent when ε-heavy chains are produced. The GFP will be attached to the secretory exon to label secretory IgE heavy chains green. The BFP will be attached to the M2 exon to label membrane IgE heavy chains blue. This will allow discrimination of mRNA processing and translation between secretory versus membrane ε-heavy chain transcripts.

30 The construct will contain an SV40 promoter-driven neomycin resistance gene which is flanked by loxP sites and inserted in the intron between the CH3 and CH4 exons (Figure 8). In addition, the HSV-TK gene will be cloned 3' of the longer homologous sequence region. U266 cells transfected with this construct will be selected for integration by culturing them in the presence of G418. The 35 surviving cells will be cultured in ganciclovir to select against cells containing the HSV-TK gene (the HSV-TK gene at the 3' end will be deleted during the desired homologous recombination event). The remaining clones will be assessed for homologous recombination by PCR. Clones containing homologously-recombined constructs will be transfected with *cre* to mediate excision of the SV40

promoter/neomycin resistance gene in order to eliminate promoter interference. Excision will be verified by subdividing clones into parent and daughter pools and re-selecting the latter pool in G418. The parental cells corresponding to G418 sensitive daughter cells will be subdivided again and tested for GFP and BFP expression. Parental stocks of the most inducible clones will be used for
5 subsequent screening.

Example 4

Development of an ϵ promoter GFP reporter cell line

- 10 The induction of the ϵ promoter in response to IL-4/13 is the first recognizable step necessary for the switch to IgE. Blocking activation of this promoter should prevent B cells from switching to IgE. Inhibitors are predicted to interfere with IL-4/13 signaling as well as nuclear transcription of the ϵ germline gene.
- 15 Three IgM⁺, EBV⁻ human B cells lines (CA-46, MC116, and DND39; see Figure 4) that produce ϵ germline transcripts in the presence of IL-4 will be infected with the following construct: a retroviral vector containing an IL-4 responsive 600 bp fragment of the ϵ promoter in the reverse orientation followed by a splice site, GFP encoding sequence and a poly-adenylation sequence (Figure 10). Briefly, cells will be infected with the reporter construct and induced with IL-4. The cells will then be
20 sorted by FACS for GFP reporter expression. The IL-4 will be removed and the cells will be sorted for the absence of reporter fluorescence. From these sorts, several clones will be established that turn on the reporter in the presence of IL-4, indicating activation of the germline ϵ promoter.

Example 5

Screening of candidate agents using reporter cell line

- 25 The cell line of Example 4 is infected with a peptide library as described above. The peptide library is packaged into infectious viral particles (see Figure 7). The library is a mixture of random peptide sequences with and without a nuclear localization sequence (NLS) upstream of a reporter
30 gene to identify infected cells and relative peptide expression (Figure 6).

- 35 Each screen will start with production of the primary retrovirus peptide library. This primary library will be used to infect at least 10^9 ϵ promoter reporter cells. After infection, the cells will be stimulated with IL-4 and two days later, the FACS will sort peptide-containing, reporter negative cells (i.e. where there is ϵ promoter inhibition). This enriched, reporter negative population will be subjected to RT-PCR to amplify the integrated peptide sequences. The PCR material will be used to construct a new "enriched" retrovirus peptide library to initiate the next screening round.

It will take approximately 5-7 rounds of enrichment to identify individual sequences capable of inhibiting the germline ϵ promoter (see discussion above regarding the statistics associated with enrichment). The most important factor that influences the number of enrichment rounds necessary to identify individual peptide hits is the ratio between real positive peptide hits in the original library and 5 heritable false positives. The frequency of real positive peptide hits is dependent upon the qualitative ability of the peptide to get to and, in the correct conformation, bind to the regulatory domains on proteins in the pathway of interest. This is why we use multiple scaffolding structures for presentation of random peptide surfaces and also different localization sequences fused to those peptide structures 10 (Appendix B). Enrichment of real positive peptides becomes less efficient with false positive rates above 2%. For this reason, great effort is placed in developing robust reporter constructs and cell lines.

Once enrichment is achieved and individual peptide sequences are shown to effect inhibition of ϵ promoter activation in an independent assay, they will be introduced into a standard set of secondary 15 and orthogonal assays. Many of these assays will be performed in primary B cells to test the specificity and physiologic characteristics of the peptide inhibitor.

Example 6

Generation of an ϵ promoter survival cell line.

20 Three different IgM $^+$, EBV $^-$ human B cells lines that produce ϵ germline transcripts in the presence of IL-4 will be infected with a survival construct carrying a death gene and a drug selectable marker 25 (Figure 10). Briefly, the retroviral construct consists of the 600 bp IL-4 inducible ϵ promoter downstream of a self-inactivating (SIN) LTR, followed by a chimeric FAS receptor (FASr), the self- cleaving peptide 2a and, lastly, the drug-selectable puromycin resistance gene. The chimeric receptor 30 is composed of the mouse FASr external domain and the human FASr transmembrane and cytoplasmic domains. A mouse specific anti-FASr antibody can be used which will bind only activated FASr produced by the survival construct. The 2a self-cleaving peptide allows equimolar amounts of the chimeric FASr and puromycin to be produced in the cell.

35 IgM $^+$ B cell lines infected with this construct in the presence of IL-4 will produce CD95, as well as puromycin resistance. Upon drug selection with puromycin, only cells containing IL-4 activated ϵ promoters will survive. The remaining cells are infected with the peptide libraries and, when cultured in the presence of IL-4 and anti-FAS (α CD95) monoclonal antibodies, will express the chimeric FAS receptor and apoptose unless their ϵ promoter has been blocked by a library peptide.

If problems arise due to over-expression of the chimeric FASr resulting in self-activation, other external domains will be used. We have already engineered a chimeric FASr containing the murine

CD8 external domain as an alternative (Figure 10). If overexpression of the chimeric FASr results in self-activation, we have designed an alternative strategy in which the proposed construct contains the GFP gene in lieu of the puromycin resistance gene (Figure 10). Due to the mild transcriptional leakiness inherent to all SIN retroviral vectors, a small percentage of IgM⁺ B cell clones infected with this construct will express low, detectable levels of GFP. These cells can be single-cell cloned by FACS, split into parent and daughter pools and tested for IL-4 inducible FASr expression-dependent apoptosis. Parent stocks of the most efficiently killed daughter cells will provide a continuous cell source for subsequent peptide screening assays. In addition, FASr ligation can be used to potentiate cell death and thus diminish background cell survival.

10

Additionally, IL-4 stimulation has been reported to diminish FAS-induced apoptosis in certain B-cell lines. To circumvent this potential difficulty, common suicide genes including Herpes Simplex Virus Thymidine Kinase (HSV-TK) or human cytochrome P450 2B1 in conjunction with ganciclovir or cyclophosphamide treatment, respectively, can replace FASr-mediated death (Figure 10).

15

Alternatively, cell cycle arrest genes such as p21 can be used in place of toxic gene products (Figure 10). In this way, cells expressing peptides which prevent IL-4 induced overexpression of p21 will have a selective growth advantage and will quickly dominate the culture.

Example 7

Screening in ϵ promoter survival cells

20

Using a peptide library generated as outlined above, the IgM⁺ B cell lines described in Example 6 are infected with the survival construct. Leaky cells (constitutive expression of the ϵ promoter) will be removed by incubation with the anti-mouse FASr antibody. Next, the cells are incubated in the presence of the inducer, IL-4, and the drug selection compound, puromycin. Cells that contain a construct that is inducible by IL-4 will be resistant and survive. This produces a population with an exogenous ϵ promoter that is IL-4 inducible. The peptide library is introduced into these cells and two days later they are induced with IL-4 in the presence of anti-mouse FASr monoclonal antibody. Cells carrying peptides that inhibit induction of the engineered ϵ promoter fragment will not produce the chimeric FASr and will survive. After the survivors grow out (approximately 1 week), they will again be subjected to IL-4 and the anti-FASr treatment. The genes encoding the peptides responsible for the survivors will be rescued by RT-PCR and used to generate an enriched retroviral library. The identification of individual inhibitory peptides should occur in only 3-4 rounds since the false positive background for survival screens is lower than for FACS-based screening. Once enrichment is achieved and individual peptide sequences are independently shown to inhibit ϵ promoter activation, these sequences will be introduced into a standard set of secondary and orthogonal assays.

25

30

35

Example 8

One-hybrid screens for identification of proteins that bind to switch ϵ region

Recombinase proteins that bind to the Se region mediate the DNA rearrangement that

5 generates a functional ϵ heavy chain. They may be specific for ϵ switching cells or may bind to other proteins that target them specifically to the Se region. Breakpoints in the recombination of the switch ϵ region to the switch μ region occur in a limited area of the switch ϵ region. Two stretches of the switch ϵ region spanning the majority of breakpoints will be used as bait in a one-hybrid screen (Figure 2b). The cDNA libraries to be used are derived from the IgE positive cell line U266 (the
10 assumption here is that the U266 line still contains the switch recombinase; certainly, the recombinase is turned off in plasma cells) and from human peripheral blood lymphocytes stimulated *in vitro* to switch with a high frequency to IgE.

15 The screening is summarized in Figure 3. The methods are as follows: Two stretches of the switch ϵ region were cloned (Figure 2A) into EcoR I/Xba I sites of pHISi-1 (Clontech) to construct a HIS reporter vector pIgE-HIS. In this construct, HIS expression is under the control of a minimal promoter and proteins binding to the switch ϵ region. Similarly, a second LacZ reporter is constructed by inserting two stretches of switch ϵ region into the EcoR I/Xho I sites of pLacZi to construct pIgE-LacZ.

20 The pIgE-HIS was linearized at an Afl II site and integrated into yeast strain YM4271 (MAT α , ura3-52, his3-200, ade2-101, lys2-801, leu2-3, 112, trp1-901, tyr1-501, gal4- Δ 512, gal80- Δ 538, ade5::hisG) to construct the first yeast reporter strain YIgE-HIS. SD-H plates were used to select for integrated
25 reporters. The yeast strain YIgE-HIS was tested on SD-H+3AT plates to determine the optimal concentration of 3AT to suppress basal level HIS expression from the minimal promoter.

30 The pIgE-LacZ plasmid was linearized at an Nco I site and integrated into the yeast strain YIgE-HIS to construct a dual reporter strain YIgE-HL. SD-U plates were used to select for cells with dual reporters integrated. The dual reporter strain will be used for transformation by the U266 cDNA library (it is assumed that the U266 line still contains the switch recombinase) and the IgE switching PBL cDNA library. At least 20 million transformants from each library will be screened on SD-LH+3AT plates. Clones that can grow up and turn blue on SD-LH+3AT plates will be grown up in SD-L liquid medium for plasmid retrieval. Retrieved cDNA clones will be further tested using *in vitro* binding assays.